(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification[7]: G03F

(21) International Application Number:
PCT/JP2003/010665

(22) International Filing Date: 22 August 2003 (22.08.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2002-242925   23 August 2002 (23.08.2002)   JP
0311470.9   19 May 2003 (19.05.2003)   GB

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(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(54) Title: PROJECTION OPTICAL SYSTEM AND METHOD FOR PHOTOLITHOGRAPHY AND EXPOSURE APPARATUS AND METHOD USING SAME

(57) Abstract: Optical Projection System and Method for Photolithography. A lithographic immersion projection system and method for projecting an image at high resolution over a wide field of view. The projection system and method include a final lens which decreases the marginal ray angle of the optical path before light passes into the immersion liquid to impinge on the image plane.

(84) **Designated States** *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

DESCRIPTION

Projection Optical System and Method for Photolithography and Exposure Apparatus and Method using same

TECHNICAL FIELD

The present invention relates to projection optical systems such as systems for photolithography.

The present invention also relates to an exposure apparatus and exposing methods. The invention is applicable to a high-resolution projection optical system suitable for an exposure apparatus used when manufacturing semiconductor elements or liquid crystal display elements through a photolithographic process.

BACKGROUND ART

In the following the term "anastigmat" means an optical element or group of optical elements adapted to reduce astigmatism and/or aberrations including spherical aberration. See, e. g. Naumann/Schröder, Bauelemente der Optik, Carl Hauser Verlag München Wien, 6th ed., 1992, pp. 382-383 for a discussion of the term anastigmat. The term "Mangin mirror arrangement" means an optical device comprising a concave mirror and at least one negative powered lens proximal to the concave mirror wherein the concave mirror need not be in contact with the negative powered lens.

In the lithographic process for manufacturing semiconductor elements or the like, it is the usual practice to use a projection exposure apparatus for exposing a pattern image of a mask (or a reticle) onto a wafer (or a glass plate or the like) coated with photoresist via a projection optical system. Along with improvement of the degree of integration of semiconductor elements, the demand for achievable resolution of a projection optical system of the projection exposure apparatus is steadily increasing.

As a result, in order to satisfy the resolution requirement of the projection optical system, it is necessary to reduce the wavelength λ of the illuminating light (exposing light) and/or increase the numerical aperture NA of the projection optical system. More specifically, the resolution of a projection optical system is expressed by $k \cdot \lambda / NA$ (where k is a process coefficient). When assuming the refractive index of a medium (usually a gas such as air) between the projection optical system and the image field to be n, and the maximum incident angle to be θ, then, the numerical aperture NA on the image side can be expressed as $n \cdot \sin \theta$.

Historically, resolution in microlithography has been improved either by increasing the numerical

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aperture (NA), or by reducing the wavelength of illumination light, or a combination of the two.

When it is tried to increase the numerical aperture by adopting a larger medium incident angle θ, the incident angle on the image plane and the outgoing angle from the projection optical system become larger, leading to an increase in reflection loss on the optical plane. It is impossible to ensure a large and effective numerical aperture on the image side. A technique is known for increasing the numerical aperture NA by filling an optical path between the projection optical system and the image field with a medium such as a liquid having a high refractive index. WO 99/49504 discloses a projection exposure method that irradiates exposure beams on a mask and transfers the pattern of said mask onto a substrate via a projection optical system, wherein when said substrate is moved along a predetermined direction, a predetermined liquid is passed along the direction of the motion of said substrate so as to fill the space between the end of the optical element on said substrate side of said projection optical system and the surface of said substrate, and discloses a projection exposure apparatus that irradiates exposure beams on a mask and transfers the pattern of said mask onto a substrate via a projection optical system, comprising a substrate

stage that moves while holding said substrate, a liquid supply device that supplies a predetermined liquid along a predetermined direction via pipes for supply so as to fill the space between the end of the optical element of said substrate side of said projection optical system and the surface of said substrate, and a liquid recovery device that recovers said liquid from the surface of said substrate via said supply pipes and pipes for discharge arranged so as to sandwich the irradiation area of said exposure beams in said predetermined direction, and wherein when said substrate stage is driven to move said substrate along said predetermined direction, supply and recovery of said liquid is performed. The direction of the flow of the liquid may be changed according to the direction of the motion of the substrate. The projection exposure apparatus may be provided with a second pair of supply pipes and discharge pipes arranged at the location where said pair of supply pipes and discharge pipes would be if they were essentially rotated by 180°. The projection exposure apparatus may also comprise a liquid recovery device that recovers liquid supplied to between said projection optical system and said substrate.

US patent no. 4,509,852 teaches using a photolithographic projection apparatus a mask having a

pattern is imaged on a photosensitive layer coating a semiconductor substrate by a projection lens. To improve the resolving capability and to obviate adverse effects, e. g. standing waves and inhomogeneous exposure, the space between the substrate and the adjacent boundary face of a projection lens is filled during exposure with a transparent liquid having the same refractive index as the photosensitive layer.

However, a concrete proposal has not as yet been made regarding a configuration which ensures a large and effective image-side numerical aperture.

The theoretical resolution improvement of liquid-immersion is well known in microscopy, where oil-immersion dioptric objectives have for many years been designed with NAs greater than 1.0, but covering only a very small field of 0.5 mm or less. See, for example: "Modern Optical Engineering", by Warren Smith, Third Edition, page 450, published by SPIE Press and McGraw Hill.

Liquid immersion applied to microlithography has also been proposed for many years, but has been slow to be adopted in production, no doubt because of practical difficulties. However, the theoretical advantages become stronger as "dry" projection lens NAs approach the theoretical limit of 1.0. These advantages have been described in, for example: "The k3 coefficient in

nonparaxial λ/NA scaling equations for resolution, depth of focus, and immersion lithography" by Burn J. Lin published in JM3 1(1) 7-12 April 2002.

More recent investigations into the practical issues of liquid immersion for lithography have also become more optimistic, for example: "Resolution enhancement of 157 nm lithography by liquid immersion" by M. Switkes and M. Rothschild, published in JM3 1(3) 225-228 October 2002. However, neither of these papers addresses the issues of optical design.

Early papers proposing liquid immersion lithography include: "Optical projection lithography using lenses with numerical apertures greater than unity" by H. Kawata, J.M. Carter, A. Yen and H.I. Smith, published in Microelectronic, Eng. 9, 31 (1989); "Fabrication of 0.2μm fine patterns using optical projection lithography with an oil immersion lens" by H. Kawata, I. Matsumura, H. Yoshida and K. Murata, published in Japan, Journal of Applied Physics, Part 131, 4174~1992; "1/8 μm optical lithography" by G. Owen, R.F.W. Pease, D.A. Markle, A. Grenville, R.L. Hsieh, R. von Bunau and N.I. Maluf, in the Journal of Vacuum Science Technology, B10-6, 3032~1992; and "Immersion lithography at 157 nm" by M. Switkes and M. Rothschild, in the Journal of Vacuum Science Technology, B19-6, 2353~2001.

The recent Switkes paper is the most significant, in that it proposes the use of water as the immersion liquid for ArF (or KrF) laser light, perfluoropolyethers for F_2 laser light, and starts to address the practical issues involved with a scanning wafer stage.

Another recent paper has started to address optical design issues for the relatively wide field of views used in lithography, partially disclosing liquid immersion dioptric microlithographic projection lens designs with NAs of greater than 1.0: "Development of dioptric projection lenses for DUV lithography" [4832-18] by Ulrich Wilhelm, Rostalski Hans-Juergen, Hudyma Russell M, published in SPIE Vol. 4832 IODC June 2002.

US 2001/0040722 A1 describes a catadioptric design which uses a V-fold mirror and two intermediate images. However, this is a small-field system (< 1 mm), specifically intended for optical inspection, and there is no indication that the design could be applied to the much larger field sizes and extremely small residual aberrations and distortion required for microlithography.

"High numerical aperture lithographic imagery at the Brewster angle" by Timothy A. Brunner et al, in JM3 1(3) 188-196, October 2002, describes the fundamental disadvantages in terms of image quality, as the NA

approaches 1.0 in a "dry" projection lens. These relate to vector imaging degradation that is made worse by Fresnel reflection losses at the resist interface, which more strongly reflects and loses the polarization

5   orientation that would have given the better image quality inside the photoresist. This occurs most strongly at Brewster's angle, which corresponds to a NA of about 0.85.

We have investigated liquid immersion dioptric

10   designs, and have found that for a NA of 1.0 and 26 mm field size the largest lens diameters need to be of the order of 330 mm, which is on the limit of available high quality fused silica, and beyond the limit for calcium fluoride. There is also a reduction in

15   spectral bandwidth, in the same way that there is for "dry" dioptric lenses as the NA increases. A reduction in field size and an increase in reduction ratio above 4x would help these issues, but would make the "wet" lithography tools incompatible with current "dry"

20   systems.

Known "dry" catadioptric designs have relatively small lens diameters and chromatic aberrations. However, they cannot be converted to liquid immersion only by adding a liquid to the space between the last

25   element and the wafer. This would introduce a large amount of spherical aberration, which has to be

compensated elsewhere in the design. Also, in simply adding a liquid, the NA does not increase, since the definition of NA already includes the refractive index.

Immersing the wafer in liquid is a necessary, but not sufficient, condition for being able to increase the NA up to the theoretical maximum equal to the liquid refractive index (~ 1.4), rather than 1.0 in a "dry" system. For a constant magnification, paraxial geometrical optics theory (in particular, the Lagrange invariant) dictates that an increase of NA at the wafer has to be accompanied by a corresponding increase in NA all the way through the projection lens system. This results in an increase in lens diameters, and optical surface steepness, defined by the ratio D/R, where D is the clear aperture diameter and R is the radius of curvature. At the same time, chromatic and high-order aberrations increase rapidly with NA.

It is therefore not obvious to one skilled in the art of optical design that the NA of a "dry" projection lens can be increased in the ratio of the refractive index of the immersion liquid, without both an impractical increase in the lens size and complexity, as well as an unacceptable increase in residual aberrations.

Textbooks on optical design (e.g. Warren Smith, Modern Optical Engineering Third Edition, page 449-450,

published by SPIE Press and McGraw Hill) describe the historical microscope immersion objective with a hyper-hemispherical convex surface (clear diameter/radius of curvature beyond hemispherical, where $D/R = 2$) on the last element, opposite the plane surface in contact with the immersion liquid. Classically, this surface is designed to be either aplanatic, or close to the aplanatic condition. At the aplanatic condition there is zero spherical aberration, coma and astigmatism, and the marginal ray convergence angle is greater inside the lens element than before it by the ratio of the glass refractive index. Being close to this aplanatic condition minimizes spherical aberration and coma, and is a simple way of increasing NA, which is useful for a small field microscope objective, or systems such as the prior art US Patent Application US 2001/0040722.

For microlithography, which requires small aberrations over a much larger field size, such an aplanatic surface would give rise to higher-order aberration variations across the field, including oblique spherical aberration and coma. It is common practice to use, instead, a convex surface on this last element that is not at the aplanatic condition, but rather at or near the so-called concentric, or monocentric condition. In the concentric situation the marginal ray convergence angle inside the last element

is identical to that incident upon it. Again there is zero spherical aberration and coma, but more importantly for a wide-field system there is zero sagittal oblique spherical aberration. See, for example, J. Dyson, JOSA, volume 49(7), p. 713 (July 1959), or, "Monocentric telescopes for microlithography" by C.G. Wynne, Optical Engineering, Vol. 26 No. 4, 1987.

J. G. Baker, The Catadioptric Refractor, The Astronomical Journal, Vol. 59, pp. 74-84 (1955) discusses pros and cons of a telescope which is based on a concept suggested by Schupmann (L. Schupmann, Die Medial-Fernrohre, Eine neue Konstruktion für große astronomische Instrumente, Teubner, Leipzig, 1899).

SUMMARY OF THE INVENTION

An object of the invention is to provide a projection optical system which permits achievement of a large and effective image-side numerical aperture by providing a medium having a high refractive index in an optical path to the image field and inhibiting satisfactorily the reflection loss on the optical surface. Another object of the invention is to provide an exposure apparatus and an exposing method which have a large and effective image-side numerical aperture and enable to transfer and expose a fine pattern at a high

accuracy via a projection optical system having a high resolution.

According to a first aspect of the invention there is provided a projection optical system for projecting an image of a first plane onto a second plane comprising: a boundary lens; and at least one layer of immersion medium between the boundary lens and the second plane; said boundary lens having a first plane side optical surface shaped such that for light projected onto the second plane through the boundary lens the marginal ray convergence angle prior to incidence is larger than the marginal ray convergence angle within said boundary lens.

According to a second aspect of the invention there is provided a projection optical system for projecting an image of a first plane to a second plane comprising: an optical system; a boundary lens; and at least one layer of immersion medium between said boundary lens and said second plane; wherein light from the first plane is transmitted through the optical system, and output with a predetermined marginal ray convergence angle; and said boundary lens is positioned to receive said light output from the optical system, and adapted such that for light projected onto the second plane through the boundary lens the marginal ray convergence angle prior to incidence is larger than the

marginal ray convergence angle within said boundary lens.

The optical system (which means the optical system of the optical projection system, where the former is included in an optical projection system) may further comprise at least one positive powered lens element proximal to said boundary lens, and having an aspheric optical surface.

Alternatively, the optical system may further comprise a first positive powered lens element proximal to said boundary lens, and having at least one aspheric optical surface, and a second positive powered lens element between the first positive powered lens element and said boundary lens, and having at least one aspheric optical surface.

The optical system may be one in which the first positive powered lens element has an axial thickness greater than 26.1mm and less than 28.9mm, and a first plane side surface with an axial radius of curvature greater than 103mm and less than 114mm, the second positive powered lens element has an axial thickness greater than 26.5mm and less than 29.3mm, and a first plane side surface with an axial radius of curvature greater than 83.2mm and less than 91.9mm, and the boundary lens has an axial thickness greater than 41.6mm and less than 46.0mm, and a first plane side

surface with an axial radius of curvature greater than 56.9mm and less than 62.9mm.

Instead, the optical system may comprise a first positive powered lens element proximal to said boundary lens, and having at least one aspheric optical surface, and a second positive powered lens element between the first positive powered lens element and said boundary lens, and having at least one aspheric optical surface, wherein the first positive powered lens element has an axial thickness greater than 27.22mm and less than 27.77mm, and a first plane side surface with an axial radius of curvature greater than 107.6mm and less than 109.8mm, the second positive powered lens element has an axial thickness greater than 27.63mm and less than 28.19mm, and a first plane side surface with an axial radius of curvature greater than 86.67mm and less than 88.42mm, and the boundary lens has an axial thickness greater than 43.37mm and less than 44.25mm, and a first plane side surface with an axial radius of curvature greater than 59.27mm and less than 60.46mm.

Any of the optical systems defined above may include a double-Gauss anastigmat arranged to reduce spherical aberration including a third positive powered lens element, a first negative powered lens element, a second negative powered lens element, and a fourth positive powered lens element.

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In this optical system the third positive powered
lens element has an axial thickness greater than 43.9mm
and less than 48.5mm, and a first plane side surface
with an axial radius of curvature greater than 128mm
and less than 141mm, the first negative powered lens
element has an axial thickness greater than 13.1mm and
less than 11.9mm, and a first plane side surface with
an axial radius of curvature greater than 1540mm and
less than 1710mm, the second negative powered lens
element has an axial thickness greater than 11.9mm and
less than 13.1mm, and a first plane side surface with
an axial radius of curvature greater than 184mm and
less than 204mm, and the fourth positive powered lens
element has an axial thickness greater than 30.6mm and
less than 33.9mm, and a second plane side surface with
an axial radius of curvature greater than 189mm and
less than 209mm.

As an alternative to the optical system described
in the preceding paragraph, the optical system may be
one in which the third positive powered lens element
has an axial thickness greater than 45.71mm and less
than 46.63mm, and a first plane side surface with an
axial radius of curvature greater than 133.3mm and less
than 136.0mm, the first negative powered lens element
has an axial thickness greater than 12.38mm and less
than 12.63mm, and a first plane side surface with an

axial radius of curvature greater than 1608mm and less than 1641mm, the second negative powered lens element has an axial thickness greater than 12.38mm and less than 12.63mm, and a first plane side surface with an

5   axial radius of curvature greater than 191.9mm and less than 195.8mm, and the fourth positive powered lens element has an axial thickness greater than 31.91mm and less than 32.56mm, and a second plane side surface with an axial radius of curvature greater than 197.4mm and

10   less than 201.3mm.

The optical system in any form as described above may comprise a catadioptric anastigmat comprising a concave mirror and at least one negative powered Schupmann lens.

15   In this optical system the catadioptric anastigmat can comprise two negative powered Schupmann lenses.

Any of the above optical systems may be adapted for use with ultraviolet light.

The optical system may comprise a set of optical

20   elements substantially having the parameters as set out in Tables 1 and 2.

The optical system may comprise a set of optical elements having parameters substantially based on those in Tables 1 and 2, but adjusted to be re-optimised for

25   a particular operating optical wavelength

According to a third aspect of the invention there is provided a method of projecting an image of a first plane onto a second plane including the steps of passing light having a first marginal ray convergence

5   angle to a boundary lens, passing light having a second marginal ray convergence angle though the boundary lens, and passing light from said boundary lens through a layer of immersion liquid to the second plane, wherein the first marginal ray convergence angle is

10   greater than the second marginal ray convergence angle.

The method may include the step of passing light through at least one positive powered lens element proximal to said boundary lens, and having an aspheric optical surface.

15   Alternatively, the method may include the steps of passing light through a first positive powered lens element proximal to said boundary lens, and having at least one aspheric optical surface, and passing light through a second positive powered lens element between

20   the first positive powered lens element and said boundary lens, and having at least one aspheric optical surface. This method may include the steps of passing light through a first positive powered lens element proximal to said boundary lens, and having at least one

25   aspheric optical surface, passing light through a second positive powered lens element between the first

positive powered lens element and said boundary lens, and having at least one aspheric optical surface, passing light through the first positive powered lens element having an axial thickness greater than 26.1mm

5   and less than 28.9mm, and a first plane side surface with an axial radius of curvature greater than 103mm and less than 114mm, passing light through the second positive powered lens element having an axial thickness greater than 26.5mm and less than 29.3mm, and a first

10   plane side surface with an axial radius of curvature greater than 83.2mm and less than 91.9mm, and passing light through the boundary lens having an axial thickness greater than 41.6mm and less than 46.0mm, and a first plane side surface with an axial radius of

15   curvature greater than 56.9mm and less than 62.9mm. Alternatively the method may include the steps of passing light through a first positive powered lens element proximal to said boundary lens, and having at least one aspheric optical surface, passing light

20   through a second positive powered lens element between the first positive powered lens element and said boundary lens, and having at least one aspheric optical surface, passing light through the first positive powered lens element having an axial thickness greater

25   than 27.22mm and less than 27.77mm, and a first plane side surface with an axial radius of curvature greater

than 107.6mm and less than 109.8mm, passing light
through the second positive powered lens element having
an axial thickness greater than 27.63mm and less than
28.19mm, and a first plane side surface with an axial
5   radius of curvature greater than 86.67mm and less than
88.42mm, and passing light through the boundary lens
having an axial thickness greater than 43.37mm and less
than 44.25mm, and a first plane side surface with an
axial radius of curvature greater than 59.27mm and less
10   than 60.46mm.

The methods as defined above may include the step
of passing light through a double-Gauss anastigmat
arranged to reduce spherical aberration including a
third positive powered lens element, a first negative
15   powered lens element, a second negative powered lens
element, and a fourth positive powered lens element.
Such methods may include the step of passing light
through a double-Gauss anastigmat arranged to reduce
spherical aberration including a third positive powered
20   lens element having an axial thickness greater than
43.9mm and less than 48.5mm, and an object side surface
with an axial radius of curvature greater than 128mm
and less than 141mm, a first negative powered lens
element having an axial thickness greater than 13.1mm
25   and less than 11.9mm, and a first plane side surface
with an axial radius of curvature greater than 1540mm

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and less than 1710mm, a second negative powered lens
element having an axial thickness greater than 13.1mm
and less than 11.9mm, and a first plane side surface
with an axial radius of curvature greater than 184mm
5   and less than 204mm, and a fourth positive powered lens
element has having axial thickness greater than 30.6mm
and less than 33.9mm, and a second plane side surface
with an axial radius of curvature greater than 189mm
and less than 209mm. Instead the method may have the
10   step of passing light through a double-Gauss anastigmat
arranged to reduce spherical aberration including a
third positive powered lens element having an axial
thickness greater than 45.71mm and less than 46.63mm,
and a first plane side surface with an axial radius of
15   curvature greater than 133.3mm and less than 136.0mm, a
first negative powered lens element having an axial
thickness greater than 12.38mm and less than 12.63mm,
and a first plane side surface with an axial radius of
curvature greater than 1608mm and less than 1641mm, a
20   second negative powered lens element has an axial
thickness greater than 12.38mm and less than 12.63mm,
and a first plane side surface with an axial radius of
curvature greater than 191.9mm and less than 195.8mm,
and a fourth positive powered lens element has an axial
25   thickness greater than 31.91mm and less than 32.56mm,

and a second plane side surface with an axial radius of curvature greater than 197.4mm and less than 201.3mm.

Any of the methods as defined above according to the third aspect of the invention may include the step of passing light through a catadioptric anastigmat comprising a concave mirror and at least one negative powered Schupmann lens, and this method may have the step of passing light through a catadioptric anastigmat comprising a concave mirror and two negative powered Schupmann lenses.

The light as used in the methods as defined above may be a beam of ultraviolet light.

The method may include the step of passing light through a set of optical elements having substantially the optical properties as set out in Tables 1 and 2.

The method may have the step of passing light through a set of optical elements substantially having optical properties based on those set out in Tables 1 and 2 but re-optimized for a particular operating wavelength.

The method may include the step of passing light through a set of optical elements substantially having optical properties based on those set out in Tables 1 and 2 but re-optimized for a particular operating wavelength and a particular immersion layer thickness.

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According to a fourth aspect of the present invention there is provided a projection optical system for projecting an image of a first plane onto a second plane, comprising:

5   an optical path having a plurality of lenses including a boundary lens which is arranged at a position closest to the second plane, wherein the first plane side surface of the boundary lens has a positive refractive power, and for an atmosphere in said optical

10   path having a refractive index of 1, the optical path between the boundary lens and the second plane is filled with a medium having a refractive index larger than 1.1.

According to a preferred embodiment of the fourth

15   aspect, the projection optical system satisfies the condition as expressed by:

$$0.012 < Cb \cdot D/NA < 0.475$$

where, Cb represents the curvature of a face of the boundary lens on the first plane side; D represents the

20   distance between an optical axis and the outermost point of an effective image forming area, and NA represents the numerical aperture on the second plane side. It is desirable that, in the projection optical system, at least one optical member having

25   substantially no refractive power is detachably arranged in the optical path between the boundary lens

and the second plane; and the optical path between the
boundary lens and the optical member, and the optical
path between the optical member and the second plane
are filled with said medium. In this case, the optical
member having substantially no refractive power has an
adjustable posture. The condition $|P \cdot D| < 1.0 \times 10^{-4}$
should preferably be satisfied, where, P represents the
refractive   power   of   the   optical   member   having
substantially no refractive power; and D represents the
distance between the optical axis and the outermost
point of the effective image forming area.

It is desirable that the projection optical system
is a reflecting/refracting optical system comprising at
least one concave reflector and a refractive optical
member.   In this case, the projection optical system
should preferably have an effective image forming area
eccentric relative to the optical axis, and at least
one intermediate image should preferably be formed in
the optical path of the projection optical system.   It
is   desirable   that   the   projection   optical   system
comprises: a first image forming optical system for
forming a first intermediate image on the first plane;
a second image forming optical system, having at least
. one   concave   reflector,   for   forming   a   second
intermediate   image   on   the   basis   of   the   first
intermediate image; and a third image forming optical

system for forming a final image on the second plane on the basis of the flux from the second intermediate image; wherein a first deflecting mirror is arranged in the optical path between the first image forming optical system and the second image forming optical system; a second deflecting mirror is arranged in an optical path between the second image forming optical system and the third image forming optical system; and the optical axis of the first image forming optical system is aligned with the optical axis of the third image forming optical system.

The numerical aperture on the first plane side should preferably be 0.22 or larger. The light quantity loss occurring upon passing through the medium should preferably be 50% or lower.

A fifth aspect of the present invention provides an exposure apparatus comprising an illuminating system for illuminating a mask set on the first plane, and a projection optical system for forming an image of a pattern formed on the mask on a photosensitive substrate set on the second plane.

A sixth aspect of the present invention provides an exposing method comprising the steps of illuminating a mask set on the first plane, and projecting and exposing a pattern image formed on the mask on a

photosensitive substrate set on the second plane via the projection optical system.

A seventh aspect of the present invention provides an exposure apparatus for transferring a pattern formed on a mask onto a photosensitive substrate comprising an illuminating optical system for illuminating a prescribed illumination area on the mask, and a projection optical system for projecting a reduced image of the pattern into an exposure area on the photosensitive substrate; wherein the projection optical system is a reflection/refraction optical system comprising a boundary lens arranged at a position the closest to the photosensitive substrate side; the exposure area is eccentric from the optical axis of the reflection/refraction-type projection optical system; and when the atmosphere in an optical path of the projection optical system is assumed to have a refractive index of 1, an optical path between the boundary lens and the second face is filled with a medium having a refractive index larger than 1.1.

In some aspects of the projection optical system of the present invention, the image-side numerical aperture NA is increased by providing a medium having a refractive index larger than 1.1 in an optical path between the boundary lens arranged at a position the closest to the image side (second plane side). The

paper "Resolution Enhancement of 157-nm Lithography by Liquid Immersion" published by M. Switkes and M. Rothchild in JM3 1(3), pp 225-228, October 2002 identifies Florinat (perfluoropolyethers: commercial

5 name by Three-M Company, the United States) and deionized water as media having a prescribed transmissivity for a beam having a wavelength λ of 200 nm or less.

The projection optical system of the present

10 invention may reduce the reflection loss on the optical surface, and finally ensure a large and effective image-side numerical aperture by imparting positive refraction power to the face of the boundary lens on the object side (first plane side). In the present

15 invention, as described below, it is possible to achieve a projection optical system which enables to keep a large and effective image-side numerical aperture by inhibiting the reflection loss on the optical surface to a satisfactory level by providing a

20 medium having a high refractive index in the optical path to the image field.

The following conditional formula (1) should preferably be satisfied. In this formula, Cb represents a curvature of the face of the boundary lens

25 facing the object; D, the distance between the optical axis and the outermost point of the effective image

forming area (in the case of an exposure apparatus, the distance between the optical axis and the outermost point of the effective exposure area); NA, the numerical aperture on the image side (the second plane side). The terms "effective image forming area" and "effective exposure area" mean an image forming area and an exposure area, of which the aberrations have been sufficiently corrected.

$$0.012 < Cb \cdot D/NA < 0.475 \quad (1)$$

A value exceeding the upper limit of the conditional formula (1) is not desirable because correction of aberration cannot sufficiently be accomplished over the entire effective image forming area (effective exposure area). A value lower than the lower limit of the conditional formula (1) is not desirable because a sufficient reduction of reflection loss on the optical surface cannot be achieved, leading to a smaller effective numerical aperture, and finally to a poorer resolution. In order to further reduce the reflection loss and an absorption loss and obtain a high resolution over the entire effective image forming area (effective exposure area), it is desirable to set an upper limit of the conditional formula (1) of 0.400, and a lower limit of 0.015.

As described above, a fluorine-based inert liquid such as Florinat or a liquid such as deionized water is

used as a medium having a high refractive index provided between the boundary lens between the boundary lens and the image field so as to make it possible to ensure a required transmissivity (to inhibit a light quantity loss). In the case of an exposure apparatus, the liquid may suffer from contamination by the photoresist coated onto a substrate such as a wafer. The contaminated liquid may stain the image-side optical surface of the boundary lens, causing a decrease in transmissivity of the boundary lens and the liquid.

Therefore, it is desirable to detachably arrange an optical member (usually an optical member having substantially no refracting power) such as a parallel flat sheet in an optical path between the boundary lens and the image field. In the manufacturing process of a projection optical system, it is possible to adjust the Petzval sum and correct curvature of the image plane by selectively replacing the optical member provided between the boundary lens and the image field.

It is furthermore desirable to adopt a configuration so as to permit adjustment of the orientation of the optical member having substantially no refractive power. In this case, asymmetrical aberration caused by lens eccentricity can be corrected by tilting the optical member relative to the optical

axis.   The optical member having substantially no
refractive   power   should   preferably   satisfy   the
following conditional formula (2):

$$|P \cdot D| < 1.0 \times 10^{-4} \qquad (2)$$

5   In the conditional formula (2), P represents the
refractive   power   of   an   optical   member   having
substantially no refractive power (= 1/focal length);
and D, the distance between the optical axis and the
outermost point of the effective image forming area (in
10   the case of an exposure apparatus, the distance between
the   optical   axis   and   the   outermost   point   of   the
effective   exposure   area).   A   value   higher   than   the
upper   limit   of   the   conditional   formula   (2)   is   not
desirable   because   it   leads   to   large   changes   in   the
15   other   aberrations   upon   correcting   the   asymmetrical
aberration by tilting the optical member.

The   projection   optical   system   should   preferably
comprise   a   reflection/refraction   optical   system   having
at   least   one   concave   reflector   and   a   refractive   optical
20   member   (lens   component).   This   configuration   permits
achievement   of   a   projection   optical   system   having   a
large   effective   image   forming   area   (effective   exposure
area)   and   a   large   image-side   numerical   aperture   NA.   In
general,   in   the   case   of   a   refractive-type   projection
25   optical   system   comprising   a   refractive   optical   member
alone,   it   is   necessary   to   bring   the   Petzval   sum   as

close to 0 as possible by alternately arranging a positive lens group and a negative lens group on the object side (near the object surface) of a smaller numerical aperture, in order to correct the field

5   curvature.

However, in an optical system having a large image-side numerical aperture, the numerical aperture is large also on the object side. It is therefore difficult to satisfactorily correct spherical

10   aberration or coma over the entire effective image forming area (effective exposure area) while correcting the Petzval sum to 0. In this case, by altering the reduction magnification from 1:4 to a reduction at higher magnification such as 1:5 or 1:6, correction of

15   the Petzval sum can be achieved because the object-side numerical aperture becomes smaller. However, when trying to ensure a wider effective exposure area in an exposure apparatus, this practice encounters the difficulty of requiring an excessively large mask.

20   In a reflection/refraction-type projection optical system having at least one concave reflector and a refractive optical system, in contrast, the concave reflector makes a contribution to the Petzval sum similar to that of a negative lens while having a

25   positive refractive power. Correction of the Petzval sum can be easily made through a combination of the

concave reflector and the positive lens. As a result,
it is possible to achieve a projection optical system
having a large image-side numerical aperture and a wide
effective image forming area (effective exposure area)

5   by a combination of a configuration of the
reflection/refraction optical system and a
configuration of a liquid-immersion optical system in
which a liquid (medium) having a high refractive index
is provided in the optical path from the image plane.

10   In the reflection/refraction optical system, a
problem is how to separate a beam directed toward the
concave reflector from a return beam reflected from the
concave reflector. In a projection optical system
having a large image-side numerical aperture, increase

15   in the effective diameter of the optical element
(adoption of larger optical elements) is inevitable.
Therefore, in a reflection/refraction optical system
using a prism-type beam splitter having a transmission
reflection surface, the difficulty is encountered that

20   it is difficult to manufacture a larger-sized prism-
type beam splitter. The projection optical system
should preferably have a configuration in which the
system has an effective image forming area eccentric
from the optical axis, and at least one intermediate

25   image is formed in the optical path. In this
configuration, it is possible to easily separate the

beam directed toward the concave reflector from the return beam reflected from the concave reflector by arranging a flat reflector for separating the optical paths near the forming position of the intermediate image.

Furthermore, the configuration should preferably be such that the projection optical system comprises a first image forming optical system which forms a first intermediate image of the object surface (the first plane); a second image forming optical system which has at lease one concave reflector and forms a second intermediate image on the basis of the flux from the first intermediate image; and a third image forming optical system which forms a final image on an image field (the second plane) on the basis of the flux from the second intermediate image; a first deflection mirror is arranged in an optical path between the first image forming optical system and the second image forming optical system; a second deflection mirror is arranged in an optical path between the second image forming optical system and the third image forming optical system; and the optical axis of the first image forming optical system agrees with the optical axis of the third image forming optical system. In this configuration, even in an optical system having a large image-side numerical aperture, it is possible to easily

separate the beam directed toward the concave reflector from the beam reflected by the concave reflector to return.   It is also possible to relatively easily accomplish assembly or adjustment of optical systems since the first image forming optical system and the third image forming optical system are coaxial.

As described above, a projection optical system conducting size reduction at a high magnification such as 1:5 or 1:6 is unfavorable in that application to an exposure apparatus results in a mask larger in size. Therefore, the object-side numerical aperture should preferably be 0.22 or larger for obtaining a high resolution at an appropriate reduction magnification. In addition, the light quantity loss caused upon passing through a medium present between the boundary lens and the image field should preferably be 50% or lower.   When this configuration requirement is not satisfied, light absorbed by the medium generates heat, and image formation tends to deteriorate under the effect of the fluctuation of the refractive index in the medium.

For a better understanding of the invention, and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows an illustration of a catadioptric "dry" projection system for comparison purposes;

Fig. 2 shows an illustration of a catadioptric liquid immersion projection lens system according to a

5   first embodiment of the present invention;

Fig. 3 shows an illustration of the last optical elements in the optical path of Fig. 2;

Fig. 4 shows an illustration of the boundary lens, the immersion liquid layer and the image plane;

10   Fig. 5 shows an illustration of the marginal ray path passing into the last lens element according to the first embodiment of the present invention;

Fig. 6 shows an illustration of the marginal ray path passing through the last lens element into the

15   immersion liquid layer according to the first embodiment of the present invention;

Fig. 7 schematically illustrates the configuration of exposure apparatus incorporating the present invention;

20   Fig. 8 illustrates the positional relationship between a rectangular effective exposure area formed on a wafer and a reference optical axis in second and third embodiments of the invention;

Fig. 9 illustrates the positional relationship

25   between a rectangular effective exposure area formed on

a wafer and a reference optical axis in a fourth embodiment;

Fig. 10 schematically illustrates the configuration of a boundary lens and a wafer in the second to fourth embodiments;

Fig. 11 illustrates the lens configuration of the projection optical system of the second embodiment of the invention;

Fig. 12 illustrates lateral aberration in the second embodiment;

Fig. 13 illustrates the lens configuration of the projection optical system of the third embodiment of the invention;

Fig. 14 illustrates the lateral aberration in the third embodiment of the invention;

Fig. 15 illustrates the lens configuration of the projection optical system of the fourth embodiment of the invention;

Fig. 16 illustrates the lateral aberration in the fourth embodiment;

Fig. 17 is a flowchart of the technique used when obtaining a semiconductor device as a microdevice;

Fig. 18 is a flowchart of the technique used when obtaining a liquid crystal display device as a microdevice;

Fig. 19 illustrates the lens configuration of a fifth embodiment of the invention; and

Fig. 20 illustrates graphs showing various aberrations of the fifth embodiment.

5   **BEST MODE FOR CARRYING OUT THE INVENTION**

Fig. 1 is an illustration of a catadioptric "dry" projection system for comparison purposes, which was disclosed in EP1191378A1. This "dry" projection system includes a first set of field lens elements L11 to L13,

10 a meniscus anastigmat L14 to L17 which aids in correcting aberrations, and a positive powered set of lens elements L18 to L20, which together comprise a first field lens group G1, a beam splitting means FM(1, 2), a Mangin mirror arrangement G2 including two

15 Schupmann lenses L21, L22 and a concave mirror CM which provides an aberration correcting function. The system also includes a positive powered set of lens elements L31 to L33, a negative lens element L34, a positive powered set of lens elements L35 and L39, a negative

20 powered anastigmat L40 which corrects aberrations, and a positive powered lens element L41 which together comprise a second field lens group G3. Light is passed from a reticle R through the first field lens group G1, then through the beam splitter FM(1, 2) to Mangin

25 mirror arrangement G2, and finally through the beam splitter FM(1, 2) and the second field lens group G3.

By this arrangement an image may be conveyed from the reticle R to a wafer W with negative magnification so as to controllably expose a photoresist on the wafer.

Figs. 2 and 3 and Tables 1 and 2 show a detailed embodiment of the invention. Light from the object plane OP passes through a plane window E201, a first positive powered group of field lens elements E202 and E203, an anastigmat E204 to E208, adapted to reduce spherical aberration, a second positive powered group of field lens elements E209 to E211, a beam splitter E212 and E218, a catadioptric anastigmat including two Schupmann lenses E213 and E214 and a concave mirror E215, the beam splitter E212 and E218 for a second time, a third positive powered group of field lens elements E219 to E221, a double-Gauss anastigmat E222 to E225 arranged to reduce spherical aberration, a fourth positive powered group of field lens elements E226 to E232, a boundary lens E233, a layer of immersion liquid IL, and to an image plane IP.

The fourth positive powered group of field lens elements includes a first positive powered lens element E231, and a second positive powered lens element E232. The double-Gauss anastigmat includes a third positive lens element E222, a first negative powered lens element E223, a second negative powered lens element E224, and a fourth positive powered lens element E225.

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In Tables 1 and 2 preferred values of the radius of curvature and the axial distances between optical surfaces of optical elements E210 to E233 are given. As those skilled in the art will appreciate, workable

5   systems may be designed in which all the parameters given in Tables 1 and 2 may be allowed to vary from the specific values given by plus or minus 1 percent, and even up to plus or minus 5 percent with appropriate adaptation. For example when operating at 157nm this

10   would give for surface S263 a radius of curvature greater than 56.9mm and less than 62.9mm, or more preferably greater than 59.27mm and less than 60.46mm, or most preferably 59.8643mm. The values for the radius of curvatures of the curved surfaces of the optical

15   elements E202 to E233 and for the thicknesses and separations of the optical elements E202 to E211, E213 to E215, and E219 to E233 will of course change if the operating wavelength is changed.

Accordingly, the thicknesses of lens elements E222

20   to E225 and E231 to E233, and the radius of curvatures of optical surfaces S240, S242, S244, S247, S259, S261 and S263 may have values as follows:

the first positive powered lens element E231 has an axial thickness greater than 26.1mm and less than

25   28.9mm, and an object side surface S259 with an axial

radius of curvature greater than 103mm and less than 114mm;

the second positive powered lens element E232 has an axial thickness greater than 26.5mm and less than 29.3mm, and an object side surface S261 with an axial radius of curvature greater than 83.2mm and less than 91.9mm;

the boundary lens E233 has an axial thickness greater than 41.6mm and less than 46.0mm, and an object side surface S263 with an axial radius of curvature greater than 56.9mm and less than 62.9mm;

the third positive powered lens element E222 has an axial thickness greater than 43.9mm and less than 48.5mm, and an object side surface S240 with an axial radius of curvature greater than 128mm and less than 141mm;

the first negative powered lens element E223 has an axial thickness greater than 11.9mm and less than 13.1mm, and an object side surface S242 with an axial radius of curvature greater than 1540mm and less than 1710mm;

the second negative powered lens element E224 has an axial thickness greater than 11.9mm and less than 13.1mm, and an object side surface S244 with an axial radius of curvature greater than 184mm and less than 204mm; and

the fourth positive powered lens element E225 has an axial thickness greater than 30.6mm and less than 33.9mm, and an image side surface S247 with an axial radius of curvature greater than 189mm and less than 209mm.

More preferably, the ranges of values for the parameters of the optical projection system are within a narrower range of plus or minus 1% of the tabulated finite values.

Accordingly, the thicknesses of lens elements E222 to E225 and E231 to E233, and the radius of curvatures of optical surfaces S240, S242, S244, S247, S259, S261 and S263 may preferably have values as follows when operating at a wavelength of 157nm:

the first positive powered lens element E231 has an axial thickness greater than 27.22mm and less than 27.77mm, and an object side surface S259 with an axial radius of curvature greater than 107.6mm and less than 109.8mm;

the second positive powered lens element E232 has an axial thickness greater than 27.63mm and less than 28.19mm, and an object side surface S261 with an axial radius of curvature greater than 86.67mm and less than 88.42mm;

the boundary lens E233 has an axial thickness greater than 43.37mm and less than 44.25mm, and an

object side surface S263 with an axial radius of curvature greater than 59.27mm and less than 60.46mm;

the third positive powered lens element E222 has an axial thickness greater than 45.71mm and less than 46.63mm, and an object side surface S240 with an axial radius of curvature greater than 133.3mm and less than 136.0mm;

the first negative powered lens element E223 has an axial thickness greater than 12.38mm and less than 12.63mm, and an object side surface S242 with an axial radius of curvature greater than 1608mm and less than 1641mm;

the second negative powered lens element E224 has an axial thickness greater than 12.38mm and less than 12.63mm, and an object side surface S244 with an axial radius of curvature greater than 191.9mm and less than 195.8mm; and

the fourth positive powered lens element E225 has an axial thickness greater than 31.91mm and less than 32.56mm, and an image side surface S247 with an axial radius of curvature greater than 197.4mm and less than 201.3mm.

Even more preferably, the values of the radius of curvature of the surfaces of the optical elements E201 to E233, and the thicknesses of the optical elements E201 to E233, have values according to Tables 1 and 2.

An important feature is the presence of a liquid (other than glass) between the image side surfaces S264 of the boundary lens 233 and the image plane IP, both of which may be plane (infinite radius of curvature) as

5   illustrated in Fig. 4. It should be noted that liquids other than water, such as perfluoropolyether, may be used in some embodiments and that the use of the term "liquid" is meant to include any fluid medium other than glass, having a refractive index substantially

10   greater than 1. Suitable liquids include water, (which may be de-ionized and/or degassed) and perfluoropolyethers.

This embodiment of the invention provides improved resolution compared with the dry microlithographic

15   projection system of Figure 1, in which the wafer is immersed in a gas. The wafer is immersed in liquid, which reduces the speed and wavelength of light incident on the photoresist by a factor of about 1.4, without changing the wavelength of the light source.

20   It thereby allows numerical apertures (NA) significantly greater than 1.0, by avoiding the total internal reflection of light that would have occurred at the last lens surface if the wafer had been immersed in a gas of refractive index close to 1.0.

25   The illustrated embodiment provides a specific "wet" catadioptric optical design at NA 1.2, a factor

of about 1.4 times higher than "dry" designs at NA 0.85 such as Fig. 1. This disclosed catadioptric design also avoids some of the practical limitations of prior art dioptric "dry" immersion optical designs.

5   In this system, the theoretical advantages of liquid immersion are realized by means of a catadioptric large-field deep ultraviolet microlithographic projection optical design, whose NA is increased beyond the theoretical limit in air of 10   1.0, without the lens diameters or surface curvatures increasing beyond practical fabrication limits, and also without a reduction in field size or spectral bandwidth of light source that would occur with prior art dioptric designs. The "wet" catadioptric NA 1.2 15   design has a track length (reticle-wafer distance) comparable to a "dry" catadioptric NA 0.85 design, and the same instantaneous wafer field size of 26 x 5 mm and a relatively small increase in lens diameters, which minimizes the changes required in the lithography 20   scanner tool body design, while allowing the same scanned fields to be covered over the wafer.

A catadioptric design is preferred (although it is not essential) because it does not require large separation of negative and positive powered lens 25   elements for field curvature correction. Instead, the field is flattened by means of a concave positive

powered mirror (element E215 in Fig. 2 and Tables 1 and 2). Negative powered lens elements close to this mirror (so-called Schupmann lenses, elements E213 and E214 in Fig. 2 and Tables 1 and 2) provide further field curvature correction and sufficient achromatization for the NA to be increased above 1.0 without the need for a second type of refracting material or a reduction in spectral bandwidth. This allows the design to be optimized for existing 0.4 pm bandwidth line-narrowed ArF excimer lasers, using only fused silica lens elements, no calcium fluoride elements, and deionized water of about 1 mm thickness as the immersion medium (IL in Fig. 2 and Tables 1 and 2).

It would be straightforward to re-optimize the disclosed design for use with a line-narrowed KrF laser. The design concept may also be applied to an F_2 excimer laser, using only calcium fluoride lens elements with for example a 0.1 mm thickness of perfluoropolyether immersion liquid layer.

Many types of prior art "dry" catadioptric designs have been designed and published. However, this invention is most closely related to, but not limited to, what may be described as the "V-type" catadioptric optical design form, which uses V-shaped fold mirrors between two intermediate images. This form has the

advantage of relatively small lens diameters and a mechanical package similar to a dioptric lens. It should however be noted that alternatives exist to the V-shaped fold mirror, such as a splitter cube which has

5   an equivalent effect.

In order to operate effectively with liquid immersion between the last lens element surface and the wafer, this last optical surface should preferably be a plane surface (surface S264 in Figs. 2 and 4 and Tables

10   1 and 2). This facilitates the liquid dynamics during wafer scanning, minimizes the possibility of bubble formation within the liquid, and minimizes sensitivity to magnification changes with liquid refractive index and dispersion (lateral color), since for a telecentric

15   system in wafer space the principal rays enter the liquid at zero angle of incidence.

In a classical liquid immersion microscope objective, the refractive index difference between the last lens element and liquid introduces spherical

20   aberration, which is minimized by using the least possible thickness of liquid and finding a liquid whose refractive index matches as closely as possible that of the lens element. In the deep-UV microlithography situation, the thickness of the liquid is chosen for

25   other reasons, such as optical transmission, as well as liquid dynamics and mechanical considerations during

45

wafer scanning and stepping. This design is not constrained by the choice of liquid thickness or refractive index. Currently, a liquid thickness of 1 mm is assumed, but the optical design may easily be re-optimized for a different thickness or liquid refractive index. Again this is facilitated by having a plane last lens surface next to the liquid, when the spherical aberration is constant across a large field size, and can be easily corrected at a pupil plane in the system by means of at least one aspheric surface.

In this invention, neither the aplanatic nor concentric conditions are used in the last element, i.e., boundary lens, next to the wafer (surface S263 on element E233, Figs. 2 and 4). In this case, the marginal ray convergence angle is slightly smaller inside element 233 than it was prior to entering it (as seen in Figs. 5 and 6). This feature has three advantages:

a. The D/R (clear diameter/radius of curvature) of this surface can be constrained to be <1.5, which is within normal optical polishing techniques for large, high quality, optical elements.

b. The resulting spherical aberration and coma may easily be corrected in other elements in the system, including several aspherical surfaces, which is advantageous in the correction of high-order

aberrations that change rapidly across the wide field used in microlithography, such as oblique spherical aberration, coma, astigmatism and distortion. This strategy is particularly effective in a long, complex system with two intermediate images, such as the V-type catadioptric design.

c. There is no focused ghost image on the wafer surface, as would occur with an exactly concentric surface.

Classical microscope objectives also employ at least one element before the last one that has a combination of aplanatic and concentric surfaces. The preferred embodiment of the invention employs, instead, at least two positive meniscus elements before the last one (elements E231 and E232 in Figs. 2 and 3 and Tables 1 and 2) whose surfaces are neither exactly concentric nor aplanatic, so as to avoid both extreme curvatures and extreme angles of incidence near or beyond the critical angle.

At least one of these surfaces may be aspheric, so as to perform similar aberration correction functions to those which in lower NA "dry" designs may be achieved with air spaces between adjacent elements (e.g. the air space between elements E230 and E231 in Fig. 2).

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The relatively high optical power in the last three positive elements minimizes the size increase of lens elements required in the rest of the system as the "dry" NA of 0.85 in designs such as Fig. 1 is increased

5   to a "wet" NA of 1.2. This is very advantageous because the lenses would otherwise be larger than can be readily made with existing technology, and would thus be exceptionally expensive. The relatively high power of the last three elements also allows a pupil

10   (aperture stop) position closer to the wafer than is typical in "dry" designs, e.g. Fig. 1.

A common feature of known catadioptric "dry" lithography projection systems is a negative powered element between the pupil and wafer. This feature,

15   which is used to correct aberrations has the disadvantage that in a "wet" catadioptric optical projection system the main positive powered lenses would have to be larger than otherwise. The new arrangement in the present application has the

20   advantage that it does not require such a negative powered lens and this further minimizes the lens diameter of the main positive powered lenses, and also the length of the optical path. The aberration correction of a negative lens element in "dry" designs

25   (e.g. element L38 in Fig. 1) is performed, instead, by an aspheric surface close to the pupil.

The negative powered lens group, elements E222 to E225 in Fig. 2, is a double-Gauss anastigmat arranged to reduce spherical aberration. It contributes to field curvature and lateral color correction in the overall design, while minimizing higher-order coma and oblique spherical aberration that would otherwise be larger at NA 1.2 than they were in "dry" designs at NA 0.85 (Fig. 1). This feature provides the advantage of allowing a wider field of view than would otherwise be possible at NA 1.2.

As illustrated in Figs. 5 and 6, it can be seen that the angle L of the marginal ray of the light cone projected to the boundary lens E233 decreases on passing into the boundary lens E233.

Figs. 5 and Fig. 6 illustrate one embodiment, where it can be seen that the geometric focus F of the marginal rays L, prior to entering the boundary lens E233, is located between the two optical surfaces S263 and S564 of the boundary lens, and is also between the centre of curvature CC of the boundary lens and the optical surface S263 of the boundary lens.

As also can be seen from Fig. 6, as the refractive index of the boundary lens E233 may typically not be equal to, and practically would be higher than, the refractive index of the layer of immersion liquid IL, the angle S of the marginal ray may increase on passing

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from the boundary lens E233 to the immersion liquid layer before impinging on the image plane IP.

It should be noted that the terms "object plane", "image plane", "pupil plane", and "plane mirror" are not limited to being plane surfaces, or plane mathematical surfaces, but may also be curved physical or mathematical surfaces. It should also be noted that the illustrations in Figures 1 to 6 are not to scale, and that the beam splitter E212, E218 may be a single element having two optical paths there through.

The aspheric surfaces A(1) to A12) in Table 1 are defined by equation (3):

$$Z = \frac{(CURV)Y^2}{1 + (1 - (1+K)(CURV)^2 Y^2)^{1\!/\!2}} + (A)Y^4 + (B)Y^6 + (C)Y^8 + (D)Y^{10}$$
$$+ (E)Y^{12} + (F)Y^{14} + (G)Y^{16} + (H)Y^{18} + (J)Y^{20}$$

(3)

CURV is the inverse value of the apex radius of curvature, and the values CURV (or Curv), A, B, C, D, E, F, G, H, and J are tabulated in Table 2.

In Table 1, the sign of the radius indicates the direction of curvature, CC indicates a concave surface and CX indicates a convex surface. In the embodiment of table 1 the largest diameter of any of the lens elements E202 to E211, E213 to 217, E219 to E228 and

50

E229 to E233 is only 242.8mm for the positive lens element 227.

Table 1

Element	Radius of Curvature			Axial distance to next surface	
	Front	Back		Back	Front
E201	Infinity	Infinity		8.0000	1.0000
E202	296.2214 CX	−960.8207	CX	29.0933	1.0000
E203	29.3195 CX	219.1233	CC	31.5402	69.4729
E204	105.2542 CX	433.274	A(1)	30.2818	1.1583
E205	77.5810 CX	85.0063 CC		35.9523	30.5076
E206	−101.0777 CC	−109.0575	CX	50.0000	22.2382
E207	−86.9124 CC	−277.5585	CX	17.0119	14.1315
E208	−313.0101 CC	−121.4285	CX	47.1365	1.0000
E209	244.5825 A(2)	−150.1716	CX	43.8716	1.0000
E210	287.8659 CX	−1006.7736	CX	33.3703	3.9387
E211	232.1539 CX	3443.7633	A(3)	26.1499	64.9981
E212	Infinity			−248.6029	
E213	99.3337 A(4)	760.1855	CX	−12.5000	−41.6713
E214	112.9332 CC	210.0532	CX	−12.5000	−23.5805
E215	150.9146 CC			23.5805	
E216	210.0532 CX	112.9332	CC	12.5000	41.6713
E217	760.1855 CX	99.3337	A(5)	12.5000	248.6029
E218	Infinity			−64.0489	
E219	3037.9516 CC	252.1281	CX	−26.2012	−1.0000
E220	−422.2688 CX	878.8560	CX	−28.0789	−1.0000
E221	−197.8858 CX	−1895.1173	CC	−36.9167	−1.0000
E222	−134.6900 CX	221.3134	A(6)	−46.1691	−18.4179
E223	−1624.3296 CX	89.3372	A(7)	−12.5000	−44.5981
E224	193.8597 CC	211.4093	A(8)	−12.5000	−14.8193
E225	−1550.8977 CX	199.3485	CX	−32.2367	−85.9268
E226	1142.6351 A(9)	305.6765	CX	−26.7479	−1.0002
E227	−341.9216 CX	−5217.2118	CC	−30.8753	−1.0000
E228	−274.1211 CX	3414.1345	A(10)	−33.1045	−9.8682
AS	Infinity			5.3722	
E229	−337.4484 CX	−6051.4400	CC	−40.2177	−1.0007
E230	−286.9832 CX	−47776.7480	CC	−29.3234	−1.0000
E231	−108.7000	152.1155	A(11)	−27.4984	−1.0000

	CX				
E232	−87.5448 CX	167.7647	A(12)	−27.9141	−1.0000
E233	−59.8643 CX	Infinity		−43.8105	
IL	Infinity	Infinity		−1.0000	

Table 2

Aspheric	Curv	K / E	A / F	B / G	C / H	D / J
A (1)	0.00230801	0.000000	1.35800E−07	4.43804E−13	5.17522E−16	−2.13416E−20
		1.24264E−23	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
A (2)	−0.00408861	0.000000	−2.93564E−09	3.96730E−13	−3.34166E−17	−3.22241E−22
		5.62462E−26	−1.64835E−30	0.00000E+00	0.00000E+00	0.00000E+00
A (3)	0.00029038	0.000000	2.58800E−08	−1.30225E−14	−1.33600E−17	7.99491E−22
		−2.36540E−26	4.15511E−31	0.00000E+00	0.00000E+00	0.00000E+00
A (4)	0.01006708	0.000000	−7.39601E−08	−3.15605E−12	−2.13807E−16	−1.63643E−20
		−2.27561E−26	−3.78485E−28	0.00000E+00	0.00000E+00	0.00000E+00
A (5)	0.01006708	0.000000	−7.39601E−08	−3.15605E−12	−2.13807E−16	−1.63643E−20
		−2.27561E−26	−3.78485E−28	0.00000E+00	0.00000E+00	0.00000E+00
A (6)	−0.00451848	0.000000	4.41668E−09	−5.79647E−13	−2.25277E−17	6.73716E−22
		−1.21801E−25	−1.34613E−30	0.00000E+00	0.00000E+00	0.00000E+00
A (7)	−0.01119354	0.000000	−6.93411E−08	−3.30971E−12	−3.11788E−16	−2.65850E−20
		−2.48878E−24	−1.79947E−28	0.00000E+00	0.00000E+00	0.00000E+00
A (8)	−0.00473016	0.000000	−4.72629E−08	6.08755E−12	−1.63469E−16	−2.65475E−20
		1.16802E−24	−3.23662E−29	0.00000E+00	0.00000E+00	0.00000E+00
A (9)	0.00087517	0.000000	1.10141E−08	−5.01692E−13	−2.00493E−17	−8.25872E−22
		3.68761E−26	2.41555E−31	0.00000E+00	0.00000E+00	0.00000E+00
A (10)	−0.00029290	0.000000	−6.20015E−09	−1.26050E−13	−3.59314E−17	1.65781E−21
		−3.84229E−26	2.58938E−31	0.00000E+00	0.00000E+00	0.00000E+00
A (11)	−0.00657395	0.000000	3.58357E−08	−7.83628E−12	7.69481E−16	−7.68364E−20
		9.31381E−25	5.59854E−28	0.00000E+00	0.00000E+00	0.00000E+00
A (12)	−0.00596073	0.000000	−1.91466E−07	4.589321E−12	1.26164E−15	4.61975E−19
		−6.00362E−23	−8.48073E−28	0.00000E+00	0.00000E+00	0.00000E+00

Fig. 7 schematically illustrates the configuration of an exposure apparatus incorporating the present invention. In Fig. 7, a Z-axis is set in parallel with a reference optical axis AX of a projection optical system PL; a Y-axis is set in parallel with the paper plane of Fig. 1, within a plane perpendicular to the reference axis AX; and an X-axis is set perpendicularly to the paper plane of Fig. 1.

The exposure apparatus shown in Fig. 7 has an ArF excimer laser source (oscillation center wavelength: 193.306 nm; used in the second and fourth embodiments) or an F_2 laser source (oscillation center wavelength:

5   157.631 nm; used in the third embodiment) as a light source 100 for supplying illuminating light of ultraviolet range. The light emitted from the light source 100 superposingly illuminates a reticle R having a prescribed pattern formed thereon via an illuminating

10   optical system IL. An optical path between the light source 100 and the illuminating optical system IL is sealed with a casing (not shown), and the space from the light source 100 to an optical member the closest to the reticle in the illuminating optical system IL is

15   substituted by an inert gas such as helium or nitrogen which is a gas having a low absorption rate of the exposure light, or kept in substantially a vacuum state.

    The reticle R is held in parallel with an XY plane

20   on the reticle stage via a reticle holder RH. A pattern to be transferred has been formed on the reticle R. A rectangular (slit-shaped) pattern area having a longer side in the X-direction in the entire pattern area and a shorter side in the Y-direction in

25   the entire pattern area is illuminated. The reticle stage RS is two-dimensionally movable along the reticle

surface (i.e., the X-Y plate) under the effect of a driving system not shown. The positional coordinates are measured by a interferometer RIF using a reticle moving mirror RM, and positionally controlled.

Light from the pattern formed on the reticle R forms a reticle pattern image on a wafer W serving as a photosensitive substrate via a projection optical system PL. The wafer W is held in parallel with the XY plane on the wafer stage WS via a wafer holder table WT. To correspond to the rectangular illuminating area on the reticle R, a pattern image is formed in the rectangular exposure area having a longer side in the X-direction and a shorter side in the Y-direction on the wafer W. The wafer stage WS is two-dimensionally movable along the wafer surface (i.e., the XY plane) under the effect of a driving system not shown. The positional coordinates thereof are measured by an interferometer WIF using a wafer moving mirror WM and positionally controlled.

Fig. 8 illustrates the positional relationship between the rectangular effective exposure area formed on the wafer and the reference optical axis in second and third embodiments of the invention. In the second and third embodiments of the invention, as shown in Fig. 8, in a circular area (image circle) IF having a radius B around the reference optical axis AX as the

center, the rectangular effective exposure area ER
having a desired size is set at a position eccentric by
A from the reference axis in the -Y direction. The
effective exposure area ER has an X-direction length LX
5   and a Y-direction length LY.

In other words, in the second and third
embodiments, a rectangular effective exposure area ER
having a desired size is set at a position apart by a
off-axis amount A from the reference optical axis AX in
10   the -Y direction, and the radius B of the circular
image circle IF is regulated so as to comprehensively
envelope the effective exposure area ER with the
reference optical axis AX as the center. In response
to this, on the reticle R, a rectangular illuminating
15   area (i.e., effective illumination area) having a size
and shape corresponding to the effective exposure area
ER is formed at a position apart from the reference
optical axis AX in the -Y direction by a distance
corresponding to the off-axis amount A.

20   Fig. 9 illustrates the positional relationship
between the rectangular effective exposure area formed
on a wafer and the reference optical axis in a fourth
embodiment of the present invention. In the fourth
embodiment of the invention, as shown in Fig. 9, in a
25   circular area (image circle) IF having a radius B
around the reference optical axis AX as the center, a

rectangular effective exposure area ER extending in a
long and thin shape in the X-direction is set with the
reference optical axis as the center. The effective
exposure area ER has an X-direction length LX and a Y-
direction length LY. Although not shown, therefore, in
response to this, a rectangular illuminating area
having a size and shape corresponding to the effective
exposure area ER around the reference optical axis AX
as the center, is formed on the reticle R.

The exposure apparatus of this embodiment has a
configuration in which, from among the optical members
forming the projection optical system PL, the interior
of the projection optical system PL is kept in an air-
tight state between the optical member arranged at a
position the closest to the reticle (in the fourth
embodiment, the lens L11) and the boundary lens Lb
arranged at a position the closest to the wafer W. The
gas in the projection optical system PL is substituted
by an inert gas such as helium gas or nitrogen or kept
substantially in a vacuum state. The reticle R, the
reticle stage RS and the like are arranged in a narrow
optical path between the illuminating optical system IL
and the projection optical system PL. The inert gas
such as nitrogen or helium gas is filled in the
interior of a casing (not shown) hermetically enclosing
the reticle R, the reticle stage RS and the like, or

the interior is maintained substantially in a vacuum state.

Fig. 10 schematically illustrates the configuration between the boundary lens and the wafer in the embodiments. In the individual embodiments, the boundary lens Lb arranged at a position the closest to the wafer of the projection optical system PL has a convex surface toward the reticle (the first face). In other words, the face Sb of the boundary lens Lb on the reticle side has a positive refractive power. A parallel flat sheet Lp is detachably inserted in the optical path between the boundary lens Lb and the wafer W. The optical path between the boundary lens Lb and the optical path between the parallel flat sheet Lp and the wafer W are filled with a medium Lm having a refractive index larger than 1.1. As the medium Lm, the second and the fourth embodiments use deionized water, and the third embodiment uses a fluorine-based inert liquid such as Florinat.

In order to continue filling the optical path between the boundary lens Lb of the projection optical system PL and the wafer W with the liquid medium Lm during a period from beginning to end of scanning exposure in an exposure apparatus based on the step-and-scan process which accomplishes scanning and exposure while moving the wafer W relative to the

projection optical system PL, for example, a technique disclosed in the above-mentioned International Publication No. WO99/49504 or a technique disclosed in Japanese Unexamined Patent Application Publication No.

5   10-303114 is applicable.

The technique disclosed in the International Publication No. WO99/49504 comprises the steps of filling an optical path between a boundary lens Lb and a wafer W with a liquid (medium Lm) of which the

10   temperature is adjusted to a prescribed level from a liquid feeder via a supply pipe and a discharge nozzle, and collecting the liquid from the wafer W by means of the liquid feeder via a collecting pipe and an inlet nozzle. The amount of supplied liquid and the amount

15   of collected liquid are adjusted in response to the moving speed of the wafer W relative to the projection optical system PL.

On the other hand, the technique disclosed in Japanese Unexamined Patent Application Publication No.

20   10-303114 comprises the steps of using a wafer holder table WT formed into a container so as to contain a liquid (medium Lm), and positioning and holding a wafer W by vacuum suction at the center of the inner bottom (in the liquid). A configuration is adopted so that

25   the body tube tip of the projection optical system is immersed in the liquid and the optical face of the

boundary lens Lb on the wafer side reaches the liquid level.

An atmosphere in which the exposure light is substantially unabsorbed is provided over the entire optical path from the light source 100 to the wafer W. As described above, the illumination area on the reticle R regulated by the projection optical system PL and the exposure area on the wafer W (i.e., the effective exposure area ER) are rectangular in shape having shorter sides running in the Y-direction. Therefore, a reticle pattern is scanned and exposed on an area having a width equal to the longer side of the exposure area and a length corresponding to the amount of scanning (amount of movement) of the wafer W on the wafer W by synchronously moving (scanning) the reticle stage RS and the wafer stage WS, i.e., the reticle R and the wafer W in the shorter-side direction of the rectangular exposure area and illumination area, while performing positional control of the reticle R and the wafer W by means of a driving system and an interferometer (RIF, WIF).

In the embodiments, the aspherical surface is expressed by the following equation (4) (which is equivalent to equation (3) using different notation) on the assumption of a height y in a direction perpendicular to the optical axis, a distance z (amount

of sagging) in the optical axis direction between a
contact plane at the apex of the asphere and a position
on the asphere at the height y, an apex radius of
curvature r, a conical coefficient κ, and an n-

5   dimensional asphere coefficient Cn.   In the
embodiments, the lens surfaces formed into aspheric
shape are marked with * to the right of the surface
numbers.

$$z = (y^2/r)/[1 + \{1 - (1 + \kappa) \cdot y^2/r^2\}^{1/2}]$$

10       $$+ C_4 \cdot y^4 + C_6 \cdot y^6 + C_8 \cdot y^8 + C_{10} \cdot y^{10}$$

$$+ C_{12} \cdot y^{12} + C_{14} \cdot y^{14} + C_{16} \cdot y^{16} + C_{18} \cdot y^{18} + C_{20} \cdot y^{20}$$

(4)

Fig. 11 illustrates the lens configuration of the
projection optical system of the second embodiment of

15   the present invention. In the second embodiment, the
projection optical system PL comprises a first image
forming optical system G1 of the refraction type for
forming a first intermediate image of the pattern of a
reticle arranged on the object surface (plane 1), a

20   second image forming optical system G2 for forming a
second intermediate image (the first intermediate image
which is a secondary image of the reticle pattern)
including a concave reflector CM, and a third image
forming optical system of the refraction type for

25   forming a final image (a reduced image of the reticle
pattern) of the reticle pattern on the wafer W arranged

on the image field (plane 2) on the basis of the light from the second intermediate image.

A first optical path bending mirror M1 for deflecting the light from the first image forming optical system G1 toward the second image forming optical system G2 is arranged near the forming position of the first intermediate image in the optical path between the first image forming optical system G1 and the second image forming optical system G2. A second optical path bending mirror M2 for deflecting the light from the second image forming optical system G2 toward the third image forming optical system G3 is arranged near the forming position of the second intermediate image in the optical path between the second image forming optical system G2 and the third image forming optical system G3.

The first image forming optical system G1 has a linearly extending optical axis AX1. The third image forming optical system G3 has a linearly extending optical axis AX3. The optical axis AX1 and the optical axis AX3 are set so as to aligned with a reference optical axis AX which is a common single optical axis. The reference optical axis AX is positioned in the gravity direction (i.e., vertical direction). As a result, the reticle R and the wafer W are arranged in parallel with each other along a plane perpendicular to

the gravity direction, i.e., along a horizontal plane. In addition, all the lenses forming the first image forming the first image forming optical system G1 and all the lenses forming the third image forming optical system G3 are arranged along the horizontal plane on the reference optical axis AX.

On the other hand, the second image forming optical system G2 also has an optical axis AX2 extending linearly, and this optical axis AX2 is set so as to be perpendicular to the reference optical axis AX. The first optical path bending mirror M1 and the second optical path bending mirror M2 have flat reflecting faces, and are integrally formed as a single optical member (a single optical path bending mirror) having two reflecting faces. The line of intersection of these two reflecting faces (strictly, the line of intersection of the virtual extension surfaces thereof) are set so as to cross AX1 of the first image forming optical system G1, AX2 of the second image forming optical system G2, and AX3 of the third image forming optical system G3 at one point.

In the second embodiment, an ArF excimer laser source is used as a light source 100. Quartz (SiO_2) is used for all the refracting optical members (lens components) forming the projection optical system PL and the parallel flat sheet Lp. The ArF excimer laser

beam which is the exposure light has an oscillation center wavelength of 193.306 nm, and quartz has a refractive index of 1.5603261 for this center wavelength. Deionized water having a refractive index of 1.47 for the exposure light is used as the medium Lm present between the boundary lens Lb and the wafer W.

In the projection optical system PL in the second embodiment, the first image forming optical system G1 comprises, sequentially from the reticles side, a positive meniscus lens L11 with a convex face thereof directed toward the reticle; a biconvex lens L12 with an aspherical convex surface or face thereof directed toward the wafer; a positive meniscus lens L13 with a convex surface thereof directed toward the reticles; a positive meniscus lens L14 with a concave surface thereof directed toward the reticle; a negative meniscus lens L15 with a concave surface thereof directed toward the reticle; a positive meniscus lens L16 with a concave surface thereof directed toward the reticle; a positive meniscus lens L17 with an aspherical concave surface thereof directed toward the reticle; a positive meniscus lens L18 with a concave face thereof directed toward the reticle; a biconvex lens L19; and a positive meniscus lens L110 with an aspherical concave surface thereof directed toward the wafer.

The second image forming optical system G2 comprises, sequentially from the reticle side (i.e., from the incident side) along the forward running path of the light, a negative meniscus lens L21 with an aspherical concave surface thereof directed toward the reticle; a negative meniscus lens L22 with a concave surface thereof directed toward the reticle; and a concave reflector CM.

The third image forming optical system G3 comprises, sequentially from the reticle side in the running direction of the light, a positive meniscus lens L31 with a concave surface thereof directed toward the reticle; a biconvex lens L32; a positive meniscus lens L33 with an aspherical concave surface thereof directed toward the wafer; a biconvex lens L34; a positive meniscus lens L35 with an aspherical concave surface thereof directed toward the reticle; a positive meniscus lens L36 with an aspherical concave surface thereof directed toward the wafer; an aperture stop AS; a biconvex lens L37; a negative meniscus lens L38 with a concave surface thereof directed toward the reticle; a positive meniscus lens L310 with a convex surface thereof directed toward the reticle; a positive meniscus lens L311 with an aspherical concave surface thereof directed toward the wafer; a positive meniscus lens L312 with a convex face thereof directed toward

the reticle; and a flat-convex lens L313 (a boundary lens Lb) with a flat surface thereof directed toward the wafer.

A parallel flat sheet Lp is arranged in the optical path between the flat-convex lens L313 serving as a boundary lens Lb and the wafer W. The optical path between the boundary lens Lb and the parallel flat sheet Lp, and the optical path between the parallel flat sheet Lp and the wafer W are filled with a medium Lm comprising deionized water.

The following Tables 3 and 4 show various parameters of the projection optical system PL of the second embodiment of Fig. 11. In Table 3, λ represents a center wavelength of the exposure light; β, a projection magnification (an image forming magnification for all the systems); NA, a numerical aperture on the image side (wafer side); B, a radius of an image circle IF on the wafer W; A, an off-axis amount of the effective exposure area ER; LX, a size (longer side size) in the X-direction of the effective exposure area ER; and LY, a size (shorter side size) in the Y-direction of the effective exposure area ER.

The surface number represents the sequence from the reticle side in the light running direction from the reticle surface which is the object surface (plane 1) toward the wafer surface which is the image·

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field (plane 2); r, curvature radii of the surfaces (in the case of an aspherical face, the apex curvature radii: in mm); d, the interval on the axis of the surfaces, i.e., the surface interval (mm); ED, the effective diameter (mm) of each surface; n, the refractive index relative to the center wavelength.

The surface interval d changes the sign every time reflection occurs. The sign of the surface interval is negative in the optical path from the reflecting surface of the first optical bending mirror M1 to the concave reflector CM and in the optical path extending from the reflecting surface of the second optical path bending mirror M2 to the image field. In the other optical paths, the sign is positive. For the first image forming optical system G1, the radius of curvature of the convex surface directed toward the reticle has a positive sign, and the radius of curvature of the concave surface has a negative sign. On the other hand, for the third image forming optical system G3, the radius of curvature toward the reticle has a positive sign, and the radius of curvature of the convex surface has a negative sign. For the second image forming optical system G2, the radius of curvature of the concave radius toward the reticle (i.e., on the incident side) has a positive sign, and the radius of curvature of the convex surface has a

negative sign. The notation in Tables 3 and 4 is used

also in the next Tables 5 and 6.

The following parameter values apply to Tables 3

and 4:

5   λ = 193.306 nm

β = -1/4

NA = 1.0

D = B = 15 mm

A = 3 mm

10   LX = 26 mm

LY = 4.4 mm

Cb = 0.01095 mm^{-1}

P = 0 mm^{-1}

Cb$\cdot$D/NA = 0.164

15      $|P\cdot D|$ = 0

Table 3

Surface No.	r (mm)	d (mm)	n	
Reticle Surface		108.2689		
501	244.17278	32.6883	1.5603261	(L11)
502	12431.0855	40.5868		
503	218.00254	43.8864	1.5603261	(L12)
504*	-901.16882	1		
505	95.35438	40.6221	1.5603261	(L13)
506	255.04609	43.5025		
507	-357.02117	25.9377	1.5603261	(L14)
508	-305.85533	29.8146		
509	-123.85265	28.7005	1.5603261	(L15)
510	-2549.65778	4.178		
511	-591.66174	23.2188	1.5603261	(L16)
512	-399.04534	8.7209		
513*	-231.3931	20.2346	1.5603261	(L17)
514	-148.33833	17.4652		
515	-354.63058	50	1.5603261	(L18)
516	-136.53902	1		

517	5811.09639	34.5332	1.5603261	(L19)
518	−219.00801	1		
519	208.57104	29.3963	1.5603261	(L110)
520*	18419.59845	90.9569		
521	∞	−244.3047		(M1)
522*	131.03687	−18.0014	1.5603261	(L21)
523	305.47877	−26.1693		
524	100.48802	−16.0009	1.5603261	(L22)
525	385.87639	−26.7822		
526	149.24479	26.7822		(CM)
527	385.87639	16.0009	1.5603261	(L22)
528	100.48802	26.1693		
529	305	18.0014	1.5603261	(L21)
530*	131.03687	244.3047		
531	∞	−64.0489		(M2)
532	529.91109	−39.4419	1.5603261	(L31)
533	219.30879	−26.0915		
534	−1009.84284	−33.6721	1.5603261	(L32)
535	345.39448	−1		
536	−176.43124	−49.9914	1.5603261	(L33)
537*	−663.25312	−119.1058		
538	205.20912	−14.0042	1.5603261	(L34)
539	−198.561	−115.1819		
540*	1437.46317	−49.9958	1.5603261	(L35)
541	188.22741	−15.3421		
542	−212.79097	−49.9776	1.5603261	(L36)
43*	−1223.58584	−25.593		
544	∞	−1.0003		(AS)
545	−15481.75066	−23.7099	1.5603261	(L37)
546	362.44209	−12.9484		
547	209.8877	−14.0041	1.5603261	(L38)
548	345.03468	−1.0007		
549	−11942.14877	−29.1119	1.5603261	(L39)
550	278.1043	−1		
551	−157.59127	−26.2942	1.5603261	(L310)
552	−333.08397	−1		
553	−127.00506	−33.438	1.5603261	(L311)
554*	−354.79236	−1.0073		
555	−119.95893	−27.9094	1.5603261	(L312)
556	−139.80778	−1		
557	−91.35661	−34.5243	1.5603261	(L313:Lb)
558	∞	−1	1.47	(Lm)
559	∞	−4	1.5603261	(Lp)
560	∞	−5	1.47	(Lm)
Wafer surface				

Table 4

Aspheric	κ C_{12}	C_4 C_{14}	C_6	C_8	C_{10}
4	0 6.02784×10^{-26}	3.88992×10^{-8} 0	-7.82619×10^{-13}	5.12223×10^{-17}	-2.73274×10^{-21}
13	0 -1.04055×10^{-24}	-6.25952×10^{-8} 3.26369×10^{-29}	5.48030×10^{-13}	-3.31838×10^{-16}	1.38375×10^{-20}
20	0 -1.24577×10^{-26}	1.72798×10^{-8} 6.24349×10^{-31}	-1.61452×10^{-13}	-4.93244×10^{-19}	1.04591×10^{-22}
22 & 30	0 -5.01578×10^{-25}	-8.82578×10^{-8} 2.58145×10^{-29}	-2.18452×10^{-12}	-8.66533×10^{-17}	-3.62594×10^{-21}
37	0 4.71865×10^{-28}	-7.06709×10^{-9} -1.92011×10^{-31}	2.17699×10^{-13}	4.99998×10^{-18}	9.16340×10^{-23}
40	0 0	5.99640×10^{-8} 0	-2.38721×10^{-13}	-2.67049×10^{-18}	8.91192×10^{-22}
43	0 -2.95585×10^{-26}	-1.17799×10^{-8} 0	-5.24366×10^{-13}	-2.67126×10^{-17}	1.52192×10^{-21}
54	0 -6.31540×10^{-25}	$-5.15363 \times 10^{-9} -$ 1.49243×10^{-29}	-2.43381×10^{-12}	6.03374×10^{-17}	2.56676×10^{-21}

Fig. 12 illustrates lateral aberration. In the aberration diagram, Y represents the image height. The notation used in Fig. 12 applies also in the subsequent Figs. 14 and 16. As is clear from the aberration diagram shown in Fig. 12, while, in the second embodiment, a very large image-side numerical aperture (NA = 1.0) is ensured by using an ArF excimer laser beam, the aberration is satisfactorily corrected over the entire effective exposure area.

Fig. 13 illustrates the lens configuration of the projection optical system of the third embodiment of the present invention. The projection optical system PL of the third embodiment is a reflection/refraction-type optical system having basically the same configuration as in the second embodiment. In the

third embodiment, however, unlike the second embodiment, an F_2 laser source is used as the light source 100. Calcium fluoride (CaF_2) is employed for all the refractive optical members (lens components) forming the projection optical system PL and the parallel flat sheet Lp. F_2 laser beam serving as the exposure light has an oscillation center wavelength of 157.631 nm, and for this center wavelength, the calcium fluoride has a refractive index of 1.5592267. A fluorine-based inert liquid having a refractive index of 1.36 to the exposure light is used as the medium Lm between the boundary lens Lb and the wafer W.

In the projection optical system PL of the third embodiment, the first image forming optical system G1 comprises, sequentially from the reticle side, a positive meniscus lens L11 with a convex surface thereof directed toward the reticle; a biconvex lens L12 with an aspherical convex surface thereof directed toward the wafer; a positive meniscus lens L13 with a convex surface thereof directed toward the reticle; a positive meniscus lens L14 with a concave surface thereof directed toward the reticle; a negative meniscus lens 115 with a concave surface thereof directed toward the reticle; a negative meniscus lens L16 with a concave surface thereof directed toward the reticle; a positive meniscus lens L17 with an

aspherical concave surface thereof directed toward the reticle; a positive meniscus lend L18 with a concave surface thereof directed toward the reticle; a biconvex lens L19; and a biconvex lens L110 with an aspherical surface thereof directed toward the wafer.

The second image forming optical system G2 comprises, sequentially from the reticle side (i.e., from the incident side) along the running path of light, a negative meniscus lens L21 with an aspherical concave surface thereof directed toward the reticle; a negative meniscus lens L22 with a concave surface thereof directed toward the reticle; and a concave reflector CM.

The third image forming optical system G3 comprises, sequentially from the reticle side along the running path of light, a positive meniscus lens L31 with a concave surface thereof directed toward the reticle; a biconvex lens L32; a positive meniscus lens L33 with an aspherical concave surface thereof directed toward the wafer; a biconvex lens L34; a positive meniscus lens L35 with an aspherical concave surface thereof directed toward the reticle; a positive meniscus lens L36 with an aspherical concave surface thereof directed toward the wafer; an aperture stop AS; a biconvex lens L37; a negative meniscus lens L38 with a concave surface thereof directed toward the reticle;

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a positive meniscus lens L310 with a convex surface thereof directed toward the reticle; a positive meniscus lens L311 with an aspherical concave surface thereof directed toward the wafer; a positive meniscus lens L312 with a convex surface thereof directed toward the reticle; and a flat convex lens L313 (boundary lens Lb) with a flat surface thereof directed toward the wafer.

A parallel flat sheet Lp is arranged in an optical path between the flat convex lens L313 serving as the boundary lens Lb and the wafer W. An optical path between the boundary lens Lb and the parallel flat sheet Lp and an optical path between the parallel flat sheet Lp and the wafer W are filled with a medium Lm comprising a fluorine-based inert liquid. In the third embodiment, in which a relatively large light quantity loss occurs upon passing through the medium Lm comprising the fluorine-based inert liquid, the distance between the parallel flat sheet Lp and the wafer W, i.e., the working distance, is set to a value considerably smaller than in the first embodiment. The following Tables 5 and 6 show various parameters of the projection optical system PL of the third embodiment. The following parameter values apply in Tables 5 and 6:

$\lambda = 157.631$ nm

$\beta = -1/4$

NA = 1.0

D = B = 15 mm

A = 3 mm

LX = 26 mm

5   LY = 4.4 mm

Cb = 0.01087 mm^{-1}

P = 0 mm^{-1}

Cb·D/NA = 0.163

|P·D| = 0

10   Table 5

Surface No.	r (mm)	d (mm)	n	
Reticle surface		101.913		
501	225.91181	34.4965	1.5592267	(L11)
502	1436.06203	33.7438		
503	201.91225	49.2729	1.5592267	(L12)
504*	−841.64457	1		
505	96.6787	38.2983	1.5592267	(L13)
506	257.84523	43.1608		
507	−380.28084	27.546	1.5592267	(L14)
508	−312.16425	30.1639		
509	−124.06734	28.9267	1.5592267	(L15)
510	−557.96151	3.8304		
511	−366.97659	22.7734	1.5592267	(L16)
512	−456.35163	12.9347		
513*	−254.00244	19.0622	1.5592267	(L17)
514	−156.7197	14.5386		
515	−336.79481	46.8839	1.5592267	(L18)
516	−133.2981	2.8796		
517	2442.55879	49.687	1.5592267	(L19)
518	−237.47884	1.195		
519	210.34651	30.7754	1.5592267	(L110)
520*	−18494.54411	86.6055		
521	∞	−256.5916		(M1)
522*	137.75129	−18	1.5592267	(L21)
523	355.77715	−27.9942		
524	100.61796	−16	1.5592267	(L22)
525	376.58992	−26.125		
526	150.70332	26.125		(CM)
527	376.58992	16	1.5592267	(L22)
528	100.61796	27.9942		

529	355.77715	18	1.5592267	(L21)
530*	137.75129	256.5916		
531	∞	−64.0489		(M2)
532	529.4817	−37.2168	1.5592267	(L31)
533	217.84933	−45.5764		
534	−906.17992	−39.8472	1.5592267	(L32)
535	390.17706	−1		
536	−175.866	−49.6987	1.5592267	(L33)
537*	−666.25803	−123.631		
538	193.90829	−14.451	1.5592267	(L34)
539	−194.01757	−115.5693		
540*	1756.45056	−49.9992	1.5592267	(L35)
541	192.14442	−16.6644		
542	−212.68601	−46.8499	1.5592267	(L36)
543*	−1313.55988	−26.5088		
544	∞	−1		(AS)
545	−46713.1214	−22.7123	1.5592267	(L37)
546	380.61069	−13.0721		
547	213.48092	−14.0147	1.5592267	(L38)
548	358.25443	−1		
549	−3283.23016	−29.4719	1.5592267	(L39)
550	287.34852	−1		
551	−177.16315	−23.5067	1.5592267	(L310)
552	−351.98397	−1		
553	−121.82696	−35.6149	1.5592267	(L311)
554*	−392.8455	−1		
555	−117.938	−28.2524	1.5592267	(L312)
556	−138.49028	−1		
557	−91.96471	−39.69	1.5592267	(L313:Lb)
558	∞	−1	1.36	(Lm)
559	∞	−4	1.5592267	(Lp)
560	∞	−1	1.36	(Lm)
Wafer surface				

Table 6

Aspheric	κ C_{12}	C_4 C_{14}	C_6	C_8	C_{10}
4	0 8.18197×10^{-26}	-4.99618×10^{-8} 0	-7.39398×10^{-13}	6.16730×10^{-17}	-3.94177×10^{-21}
13	0 -5.93253×10^{-25}	-6.25952×10^{-8} 1.35088×10^{-29}	1.42305×10^{-12}	-2.81530×10^{-16}	1.39566×10^{-20}
20	0 -1.38926×10^{-26}	1.68383×10^{-8} 5.21818×10^{-31}	-1.06688×10^{-13}	-2.92682×10^{-18}	2.12089×10^{-22}
22 and 30	0 -7.40500×10^{-26}	-8.30158×10^{-8} -9.34635×10^{-30}	-1.66607×10^{-12}	-6.51740×10^{-17}	-4.60984×10^{-21}
37	0 -5.40821×10^{-29}	-5.68895×10^{-9} -2.41357×10^{-31}	2.19286×10^{-13}	5.12916×10^{-18}	6.51778×10^{-23}
40	0 0	5.94153×10^{-8} 0	-2.72431×10^{-13}	-3.72411×10^{-18}	8.85563×10^{-22}
43	0 -3.00290×10^{-26}	-1.10623×10^{-8} 0	-5.34092×10^{-13}	-2.58209×10^{-17}	1.51679×10^{-21}
54	0 -7.25627×10^{-25}	-5.82309×10^{-9} 2.57401×10^{-29}	-2.25140×10^{-12}	6.80911×10^{-17}	3.12945×10^{-21}

Fig. 14 illustrates the lateral aberration in the third embodiment. As is evident from the aberration diagram shown in Fig. 14, in the third embodiment, while a very large image-side numerical aperture (NA = 1.0) is kept, the aberration is satisfactorily corrected over the entire effective exposure area.

Fig. 15 illustrates the lens configuration of the projection optical system of a fourth embodiment of the present invention. The projection optical system PL is a refraction-type optical system, unlike the first, second and third embodiments. However, in the fourth embodiment, as in the second embodiment, an ArF excimer laser source is used as the light source 100, and deionized water having a refractive index of 1.47 relative to the exposure light is used as the medium Lm provided between the boundary lens Lb and the wafer W.

In the fourth embodiment, quartz (SiO_2) or calcium fluoride (CaF_2) is used for the refractive optical member (a lens component) and the parallel flat sheet Lp forming the projection optical system PL. More specifically, lenses L13, L17, L18, L114, L115, L122 and L123 (Lb) are formed from calcium fluoride, and the other lenses and the parallel flat sheet Lp are formed from quartz. The ArF excimer laser beam serving as the exposure light has an oscillation center wavelength of 193.306 nm. Quartz has a refractive index of 1.5603261 for this center wavelength, and calcium fluoride has a refractive index of 1.5014548.

The projection optical system PL of the fourth embodiment comprises, sequentially from the reticle side, a biconcave lens L11 with an aspherical concave surface thereof directed toward the wafer; a negative meniscus lens L12 with a concave surface thereof directed toward the reticle; a positive meniscus lens L13 with a concave surface thereof directed toward the reticle; a positive meniscus lens L14 with an aspherical concave surface thereof directed toward the reticle; a positive meniscus lens L16 with a convex surface thereof directed toward the reticle; a positive meniscus lens L17 with a convex surface thereof directed toward the reticle; a positive meniscus lens L18 with a convex surface thereof directed toward the

reticle; a negative meniscus lens L19 with a convex surface thereof directed toward the reticle; a biconcave lens L110 with an aspherical concave surface thereof directed toward the reticle; a biconcave lens L111 with an aspherical concave surface thereof directed toward the wafer; a biconcave lens L112 with an aspherical concave surface thereof directed toward the wafer; a positive meniscus lens L113 with an aspherical concave surface thereof directed toward the wafer; a biconvex lens L114; a biconvex lens L115; a negative meniscus lens L116 with a convex surface thereof directed toward the reticle; an aperture stop AS; a biconcave lens L117; a positive meniscus lens L118 with a concave surface thereof directed toward the reticle; a biconvex lens L119; a positive meniscus lens L120 with a convex surface thereof directed toward the reticle; a positive meniscus lens L121 with an aspherical concave surface thereof directed toward the wafer; a positive meniscus lens L122 with a convex surface thereof directed toward the reticle; and a negative meniscus lens L123 (boundary lens Lb) with a convex surface thereof directed toward the reticle.

A parallel flat sheet Lp is arranged in an optical path between the negative meniscus lens L123 serving as a boundary lens Lb and the wafer W. An optical path between the boundary lens Lb and the parallel flat

sheet Lp and an optical path between the parallel flat sheet Lp and the wafer W are filled with a medium Lm comprising deionized water.

5   The following Tables 7 and 8 show parameters of the projection optical system PL of the fourth embodiment. In Table 7 and 8, λ represents the center wavelength of the exposure light; β, a projection magnification (image forming magnification ·for the entire system); NA, the numerical aperture on the image

10   side (wafer side); B, the radius of an image circle on the wafer W; LX, the size (the size of the longer side) of the effective exposure area ER in the X-direction; and LY, the size (the size of the shorter side) of the effective exposure area ER in the Y-direction.

15   The surface number represents the sequence of a surface from the reticle side in the light running direction from the reticle surface which is the object surface (surface 1) to the wafer surface which is the image field (surface 2); r represents the radius of

20   curvature of each surface (apex radius of curvature in the case of an aspherical surface: in mm); d, the interval on the axis of each surface, i.e., the surface interval (mn); ED, the effective diameter (mm) of each surface; and n, the refractive index for a center

25   wavelength. It is assumed that the radius of curvature of a convex surface directed toward the reticle is

positive, and a concave surface has a negative radius
of curvature. The following parameter values apply in
Tables 7 and 8:

λ = 193.306 nm

5   β = -1/4

NA = 0.9

D = B = 12 mm

LX = 22 mm

LY = 9 mm

10   Cb = 0.002 mm^{-1}

P = 0 mm^{-1}

Cb·D/NA = 0.0267

|P·D| = 0

Table 7

Surface No.	r (mm)	d (mm)	n	
	(Reticle face)	55.8515		
501	-2113.36467	22.0016	1.5603261	(L11)
502*	216.83131	37.6588		
503	-99	35.9329	1.5603261	(L12)
504	-530.65397	1		
505	-2085.24301	49.6884	1.5014548	(L13)
506	-211.94203	1		
507*	-1300.49159	51	1.5603261	(L14)
508	-228.7234	1		
509	449.54298	42.9915	1.5603261	(L15)
510	-31743139.73	4.4564		
511	286.16093	46.424	1.5603261	(L16)
512	700	27.3629		
513	200	44.5225	1.5014548	(L17)
514	835.17809	1		
515	176.47058	44.0153	1.5014548	(L18)
516	4997.43477	1		
517	1190.04003	14.0931	1.5603261	(L19)
518	117.90394	42.896		
519*	-174.99987	14	1.5603261	(L110)
520	122.55049	22.0064		

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521	−9702.06368	10	1.5603261	(L111)
522*	501.0497	22.5348		
523	−150	15.2478	1.5603261	(L112)
524*	545.44066	5.0208		
525	670.66815	37.0463	1.5603261	(L113)
526*	1258.71661	9.9406		
527	5070.2394	51.1959	1.5014548	(L114)
528	−161.64547	1		
529	827.78244	41.9662	1.5014548	(L115)
530	−354.18335	2.2506		
531	4796.10166	21.3348	1.5603261	(L116)
532	2003.44485	100.6473		
534	∞	19.4869		(AS)
534	−1507.37025	26.9184	1.5603261	(L117)
535	1249.53353	17.3121		
536	−3874.77086	48.5508	1.5603261	(L118)
537	−333.94853	1		
538	1503.93894	41.7658	1.5603261	(L119)
539	−563.59244	1		
540	186	57.7875	1.5603261	(L120)
541	997.61736	1		
542	158.43716	36.3731	1.5603261	(L121)
543*	202.36197	1		
544	120	48.8077	1.5014548	(L122)
545	244.45698	7.8937		
546	500	45.5175	1.5014548	(L123:Lb)
547	100.78932	4.5	1.47	(Lm)
548	∞	4	1.5603261	(Lp)
549	∞	9	1.47	(Lm)
550				
551	−177.16315	−23.5067	1.5592267	(L310)
552	−351.98397	−1		
553	−121.82696	−35.6149	1.5592267	(L311)
554*	−392.8455	−1		
555	−117.938	−28.2524	1.5592267	(L312)
556	−138.49028	−1		
557	−91.96471	−39.69	1.5592267	(L313:Lb)
558	∞	−1	1.36	(Lm)
559	∞	−4	1.5592267	(Lp)
560	∞	−1	1.36	(Lm)
Wafer				

Table 8

Aspheric	κ C_{12}	C_4 C_{14}	C_6	C_8	C_{10}
2	0 -2.03062×10^{-24}	-1.49703×10^{-7} 5.69043×10^{-29}	6.71854×10^{-12}	-3.64562×10^{-16}	4.13593×10^{-20}
7	0 1.74725×10^{-28}	-1.18880×10^{-8} -4.32881×10^{-32}	1.02901×10^{-13}	-7.54528×10^{-19}	5.83141×10^{-23}
19	0 3.26842×10^{-24}	-7.74045×10^{-8} -3.56309×10^{-28}	1.56057×10^{-11}	-1.10312×10^{-15}	3.62488×10^{-20}
22	0 -4.51996×10^{-24}	-1.04821×10^{-7} 4.81943×10^{-28}	8.80831×10^{-12}	3.69747×10^{-17}	-2.96855×10^{-20}
24	0 -8.61747×10^{-25}	1.27905×10^{-8} -7.01397×10^{-29}	7.05643×10^{-13}	-4.87282×10^{-16}	4.68907×10^{-20}
26	0 -4.70258×10^{-25}	7.26173×10^{-8} 1.17373×10^{-29}	-3.04123×10^{-12}	-2.32724×10^{-17}	8.20189×10^{-21}
43	0 3.04007×10^{-27}	-1.90186×10^{-8} 4.59309×10^{-31}	-8.61256×10^{-14}	1.45348×10^{-17}	4.84634×10^{-24}

Fig. 16 illustrates a lateral aberration in the fourth embodiment. As is clear from the aberration diagram shown in Fig. 16, in the fourth embodiment, while a relatively large image-side numerical aperture (NA = 0.9) is maintained by using an ArF excimer laser beam in the refraction-type projection optical system, the aberration is satisfactorily corrected over the entire effective exposure area.

Thus, in the second embodiment, it is possible to ensure a high image-side numerical aperture of 1.0 for the ArF excimer laser beam having a wavelength of 193.306 nm and maintain a rectangular effective exposure area (stationary exposure area) having a size of 26 mm x 4.4 mm as an area in which various aberrations are sufficiently corrected within an image circle having a radius of 15 mm on the wafer W. For

example, a circuit pattern can be scanned and exposed at a high resolution within a 26 mm x 33 mm rectangular exposure area.

In the third embodiment, it is possible to ensure a high image-side numerical aperture of 1.0 for the F_2 laser beam having a wavelength of 157.631 nm and maintain a rectangular effective exposure area (stationary exposure area) having a size of 26 mm x 4.4 mm as an area in which various aberrations are sufficiently corrected within an image circle having a radius of 15 mm on the wafer W. For example, a circuit pattern can be scanned and exposed at a high resolution within a 26 mm x 33 mm rectangular exposure area.

In the fourth embodiment, it is possible to ensure a high image-side numerical aperture of 0.9 for the ArF excimer laser beam having a wavelength of 193.306 nm and maintain a rectangular effective exposure area (stationary exposure area) having a size of 22 mm x 9 mm as an area in which various aberrations are sufficiently corrected within an image circle having a radius of 12 mm on the wafer W. For example, a circuit pattern can be scanned and exposed at a high resolution within a 22 mm x 33 mm rectangular exposure area.

While, in the second embodiment, all the lens components are made of quartz, the risk of deterioration of the image forming function caused by

the compaction of quartz can be avoided by forming
small-diameter lenses from calcium fluoride, on which
the energy of exposure light concentrates (such as the
boundary lens Lb arranged near the wafer W or the lens
L312).

If it is preferable to limit the condition
relating to the magnification of the third imaging lens
group, the conditional expression can be limited as
follows:

$$0.75 < MA/MG3 < 1.1 \qquad (5)$$

preferably $0.8 < MA/MG3 < 1.05$

where MA denotes a magnification of the whole
optical system, and MG3 denotes a magnification of the
third imaging lens system G3.

When a numerical aperture NA for light entering to
the plane mirror having the role of separating optical
paths becomes large, it becomes difficult to separate
optical paths, so that it becomes necessary that the
distance between the optical axis and the exposure area
is made to be large. In order to secure sufficient
exposure area, it is inevitable that the optical system
becomes large. Even if a large numerical aperture NA is
expected on the image side, by satisfying a conditional
expression regarding the magnification of the third
imaging lens group, the increase in numerical aperture
on entering the plane mirror is gentle, so that optical

path separation can be made easier. Accordingly, a large numerical aperture NA on the image side is secured and good optical performance can be obtained without causing the optical system to become large.

In order to make the numerical aperture NA large and to prevent the diameter of lenses locating in the vicinity of the aperture stop getting larger, it is necessary to shorten the distance between the aperture stop and the image plane (second plane) as well as to increase the composite positive refractive power of the focusing lens group arranged between the aperture stop and the image plane. At the same time, in order to prevent lens deformation caused by holding a lens element, it is necessary to secure sufficient edge thickness of a lens, so that it is preferable that the focusing lens group is composed of five lens elements or less. Moreover, in order to increase positive refractive power effectively, it is preferable that the focusing lens group does not include a negative lens element.

For reference purposes, the following summarises the overall magnification MA and the magnification MG3, of the third stage G3 in various embodiments.

Magnification   MA

MG3   MA/MG3

1st Embodiment   1/4

1/3.55   0.888

2nd Embodiment(ArF)   1/4

1/3.53   0.883

5   3rd Embodiment(F$_2$)   1/4

1/3.78   0.945

5th Embodiment   1/4

1/3.42   0.855

Tables 9 and 10 show various values associated

10 with the fifth embodiment.

The following parameters apply in the fifth

embodiment shown in Fig. 19:

NA (image side): 1.25

Magnification MA: 1/4

15 Exposure area: A=3.5 mm, B=15.1 mm

→rectangular area 26 mm×4 mm

Central Wavelength: 193.306 nm

Refractive index of silica glass: 1.5603261

Refractive index of purified water: 1.4368163

20 Dispersion of silica glass (dn/dλ): -1.591E-6/pm

Dispersion of purified water (dn/dλ): -2.096E-6/pm

In the meantime one example of the immersion

liquid for the photolithography machine using F$_2$ laser

is perfluoropolyether (PFPE).

25 In the projection optical system PL in the fifth

embodiment of Fig. 19, the first image forming optical

system G1 comprises, sequentially from the reticle side, a positive lens L11 with a convex surface thereof directed toward the reticle; a positive meniscus lens L12 with a convex surface thereof directed toward the reticle; a biconvex lens L13 with wafer side aspheric surface; a positive meniscus lens L14 with a convex surface thereof directed toward the reticle; a positive meniscus lens L15 with a concave surface thereof directed toward the reticle; a negative meniscus lens L16 with a concave surface thereof directed toward the reticle; a positive meniscus lens L17 with concave surface thereof directed toward the reticle; a positive meniscus lens L18 with aspheric concave surface thereof directed toward the reticle; a positive lens L19; and a positive meniscus lens L110 with aspheric surface thereof directed toward the wafer.

The second image forming optical system G2 comprises, sequentially from the reticle side (i.e., from the incident side) along the forward running path of the light, a negative meniscus lens L21 with an aspherical concave surface thereof directed toward the reticle; a negative meniscus lens L22 with a concave surface thereof directed toward the reticle; and a concave reflector CM.

The third image forming optical system G3 comprises, sequentially from the reticle side in the running direction of the light, a positive meniscus lens L31 with a concave surface thereof directed toward the reticle; a biconvex lens L32; a positive lens L33; a positive meniscus lens L34 with an aspherical concave surface thereof directed toward the wafer; a biconcave negative lens L35 with an aspherical concave surface thereof directed toward the wafer; a negative meniscus lens L36 with an aspherical concave surface thereof directed toward the wafer; a biconvex lens L37; a positive lens L38 with an aspherical surface thereof directed toward the reticle; apositive meniscus lens L39 with a convex surface thereof directed toward the reticle; a positive lens L310 with an aspherical surface thereof directed toward the wafer; an aperture stop AS; a bicovex lens L311; a positive lens L312; a positive meniscus lens L313 with a concave aspheric surface thereof directed toward the wafer; a positive meniscus lens L314 with a concave aspheric surface thereof directed toward the wafer; and a flat-convex lens L315 (a boundary lens Lb) with a flat face thereof directed toward the wafer.

As is apparent from Fig. 20, the fifth embodiment achieves excellent correction for chromatic aberration within wavelength scope of ±0.4 pm.

Table 9

Surface No.	r (mm)	d (mm)	Material
Object Plane	∞	81.9091	
601:	2634.49417	21.2504	fused silica
602:	−395.77168	1.0000	
603:	150.00000	50.0000	fused silica
604:	369.68733	54.9152	
605:	179.71446	34.0868	fused silica
606:	ASP−1	6.6932	
607:	88.93816	50.0000	fused silica
608:	91.86919	23.6059	
609:	−98.63242	50.0000	fused silica
610:	−88.50693	12.0495	
611:	−76.47008	38.6573	fused silica
612:	−344.46033	15.7028	
613:	−334.92667	50.0661	fused silica
614:	−117.23873	1.0000	
615:	ASP−2	43.8716	fused silica
616:	−181.49712	1.0000	
617:	289.19628	27.8483	fused silica
618:	5892.12201	12.1517	
619:	227.01362	27.1570	fused silica
620:	ASP−3	69.0000	
621:	∞	−236.5116	(M1)
622:	ASP−4	−12.5000	fused silica
623:	1144.45984	−50.1326	
624:	110.85976	−12.5000	fused silica
625:	213.24820	−26.1588	
626:	155.15866	26.1588	(CM)
627:	213.24820	12.5000	fused silica
628:	110.85976	50.1326	
629:	1144.45984	12.5000	fused silica
630:	ASP−4	236.5116	
631:	∞	−64.0489	(M2)
632:	3037.95158	−22.3312	fused silica
633:	259.31045	−1.0000	
634:	−470.92323	−24.5450	fused silica
635:	700.75092	−1.0000	
636:	−228.28898	−45.9798	fused silica
637:	−4362.49907	−1.0000	
638:	−147.00156	−50.0000	fused silica
639:	ASP−5	−13.1758	
640:	810.59426	−12.5000	fused silica
641:	ASP−6	−40.9252	
642:	−2113.41076	−12.5000	fused silica
643:	ASP−7	−16.1803	

644:	−562.31334	−30.6877	fused silica
645:	1126.64825	−80.2339	
646:	ASP−8	−22.6585	fused silica
647:	586.42327	−1.0000	
648:	−361.03935	−33.1534	fused silica
649:	−3170.02757	−1.0000	
650:	−310.02927	−49.2493	fused silica
651:	ASP−9	−9.8682	
652:	∞	−5.3722	Aperture Stop
653:	−777.31707	−35.8824	fused silica
654:	1312.61222	−1.0007	
655:	−319.73575	−35.9439	fused silica
656:	3225.49072	−1.0000	
657:	−130.49530	−28.4950	fused silica
658:	ASP−10	−1.0000	
659:	−95.22134	−34.3036	fused silica
660:	ASP−11	−1.0000	
661:	−61.85167	−50.0000	fused silica
662:	∞	−1.0000	deionized water
image plane	∞		

Table 10

Aspheric No.	Curvature (CURV)	K	A	B	C	D
		E	F	G	H	J
ASP−1	−0.00209291	0	7.81812×10^{-8}	6.03387×10^{-13}	3.16794×10^{-16}	-3.45599×10^{-20}
		1.67268×10^{-24}	0	0	0	0
ASP−2	−0.00252981	0	-1.14607×10^{-08}	4.60861×10^{-13}	-1.61766×10^{-17}	-5.41414×10^{-24}
		5.36076×10^{-27}	-1.16131×10^{-31}	0	0	0
ASP−3	0.00029038	0	1.29530×10^{-08}	2.79320×10^{-13}	-1.95862×10^{-17}	6.49032×10^{-22}
		-1.02409×10^{-26}	-4.06450×10^{-32}	0	0	0
ASP−4	0.00934352	0	-8.88014×10^{-08}	-3.40911×10^{-12}	-1.98985×10^{-16}	-1.45801×10^{-20}
		-9.23066×10^{-26}	-1.30730×10^{-28}	0	0	0
ASP−5	−0.00197848	0	-3.21829×10^{-08}	4.08976×10^{-13}	9.46190×10^{-17}	-1.12686×10^{-20}
		1.09349×10^{-24}	-2.30304×10^{-29}	0	0	0
ASP−6	−0.0104007	0	-1.40846×10^{-08}	3.73235×10^{-12}	5.78170×10^{-17}	4.02044×10^{-20}
		1.81116×10^{-24}	-3.46502×10^{-28}	0	0	0
ASP−7	−0.00689746	0	3.76564×10^{-08}	2.04565×10^{-12}	6.72661×10^{-17}	3.35779×10^{-21}
		-5.51576×10^{-25}	2.95829×10^{-28}	0	0	0
ASP−8	−0.00029365	0	1.54429×10^{-08}	-1.52631×10^{-13}	-1.17235×10^{-17}	-3.02626×10^{-22}
		-2.05070×10^{-28}	3.61487×10^{-31}	0	0	0
ASP−9	0.00123523	0	-9.78469×10^{-09}	2.15545×10^{-14}	-2.66488×10^{-17}	1.19902×10^{-21}
		-2.50321×10^{-26}	2.10016×10^{-31}	0	0	0
ASP−10	−0.00508157	0	2.76215×10^{-09}	-4.06793×10^{-12}	4.51389×10^{-16}	-5.07074×10^{-20}
		1.83976×10^{-24}	-6.22513×10^{-29}	0	0	0
ASP−11	−0.00460959	0	-1.08228×10^{-07}	-9.51194×10^{-12}	1.14605×10^{-15}	-1.27400×10^{-19}
		1.59438×10^{-23}	-5.73173×10^{-28}	0	0	0

The exposure apparatus in the above-mentioned embodiments makes it possible to manufacture microdevices (such as semiconductor devices, image pickup devices, liquid crystal display devices and thin-film magnetic heads) by illuminating a reticle (mask) by an illuminating apparatus (illuminating step), and exposing a pattern for transfer formed on the mask onto a photosensitive substrate by means of a projection optical system. A typical technique for obtaining a semiconductor device as a microdevice by forming a prescribed circuit pattern on a photosensitive substrate such as a wafer by using the exposure apparatus of this embodiment will be described with reference to a flowchart shown in Fig. 17.

In step 301 shown in Fig. 17, metal films are vapor-deposited onto wafers of one batch. In the next step 302, photoresist is coated onto these metal films on the wafers of the batch. Subsequently in step 303, the pattern images on the masks are sequentially exposed and transferred in the individual shot areas on the wafers of the batch by using the exposure apparatus of this embodiment. Thereafter, after development of the photoresist on the wafers of the batch in step 304, circuit patterns corresponding to the patterns on the masks are formed in the individual shot areas on the

wafers by conducting etching with the resist patterns as masks on the wafers of the batch.

Then, a device such as a semiconductor device is manufactured by forming the circuit pattern of an upper layer. According to the above-mentioned semiconductor device manufacturing method, a semiconductor device having a very fine circuit pattern can be obtained at a high throughput. In steps 301 to 305, a metal is vapor-deposited on the wafer; a resist is coated onto the metal film; and exposure, development and etching steps are performed. Prior to performing these steps, after forming a silicon oxide film on the wafer, resist may be coated onto the silicon oxide film, followed by exposure, development and etching steps.

According to the exposure apparatus of this embodiment, it is possible to obtain a liquid crystal display device as a microdevice by forming a prescribed pattern (a circuit pattern, an electrode pattern or the like) on a plate (glass substrate). A typical technique applied at this stage will be described with reference to the flowchart shown in Fig. 12. In Fig. 18, in the pattern forming step 401, a photolithographic step is executed through transfer and exposure of the pattern of the mask onto the photosensitive substrate (a glass substrate having a resist coated thereon, or the like) by using the

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exposure apparatus of this embodiment. As a result of this photolithographic process, many prescribed patterns including electrodes and the like are formed on the photosensitive substrate. The prescribed

5   patterns are formed on the exposed substrate through steps such as developing, etching and resist stripping steps, and the process advances to the next color filter forming step 402.

Then, in the color filter forming step 402, many

10   sets of these kinds of dots including R (red), G (green) and B (blue) are arranged in a matrix shape, or a plurality of sets of stripe filters of R, G and B are arranged in the horizontal scanning lines, to form a color filter. After the color filter forming step 402,

15   a cell assembling step 403 is executed. In the cell assembling step 403, a liquid crystal panel (liquid crystal cell) is assembled by using the substrate having prescribed patterns resulting from the pattern forming step 401, and the color filter obtained in the

20   color filter forming step 402. In the cell assembling step 403, a liquid crystal is injected into the space between, for example, the substrate having the prescribed patterns resulting from the pattern forming step 401 and the color filter obtained in the color

25   filter forming step 402, to manufacture a liquid crystal panel (liquid crystal cell).

Subsequently, in a module assembling step 404, component parts such as an electric circuit causing the assembled liquid crystal panel (liquid crystal cell) and backlights are attached, thus completing a liquid crystal display device. According to the above-mentioned manufacturing method of liquid crystal display devices, it is possible to obtain a liquid crystal display device having very fine circuit patterns at a high throughput.

In the aforementioned embodiments, the present invention is applied to the exposure apparatus based on the step-and-scan process in which a mask pattern is scanned and exposed to exposure areas of the substrate while moving the mask and substrate relative to the projection optical system. The present invention is not however limited to this, but is applicable also to an exposure apparatus of the step-and-repeat process in which the mask pattern is transferred in a lump onto the substrate in a stationary state of the mask and the substrate, and the mask patterns are sequentially exposed onto the exposure areas by successively moving the substrate stepwise.

In the aforementioned embodiments, an ArF excimer laser source or an F_2 laser source is used. The present invention is not however limited to this, but other appropriate light source may be employed. The

present invention is applied in the aforementioned embodiments to a projection optical system mounted on an exposure apparatus. While the present invention is applied to a projection optical system mounted on an exposure apparatus, the present invention is not limited to this, but is applicable also to other popularly used projection optical systems.

According to the projection optical of the present invention, as described above, occurrence of reflection loss on an optical face can be satisfactorily inhibited, and a large effective image-side numerical aperture can be maintained by providing a medium having a high refractive index in the optical path to the image field, and imparting a positive refractive power onto the face of the boundary lens on the object side.

Therefore, in the exposure apparatus and the exposing method using the projection optical system of the present invention, a fine pattern can be transferred and exposed at a high accuracy via the projection optical system having a large and effective image-side numerical aperture and a high resolution. A satisfactory microdevice through high-accuracy projection and exposure via a high-resolution projection optical system by using an exposure apparatus mounting the projection optical system of the present invention.

CLAIMS

1.   A projection optical system for projecting an image of a first plane (OP) onto a second plane (IP) comprising:

5   a boundary lens (E233); and

at least one layer of immersion liquid (IL) between the boundary lens (E233) and the second plane (IP);

said boundary lens (E233) having a first plane side optical surface (S263) shaped such that for light

10   projected onto the second plane (IP) through the boundary lens (E233) the marginal ray convergence angle (L) prior to incidence is larger than the marginal ray convergence angle (S) within said boundary lens (E233).

2.   The projection optical system of Claim 1 further

15   comprising:

at least one positive powered lens element (E231, E232) proximal to said boundary lens (E233), and having an aspheric optical surface (S259, S260, S261, S262).

3.   The projection optical system of Claim 1 wherein

20   there are provided:

a first positive powered lens element (E231) proximal to said boundary lens (E233), and having at least one aspheric optical surface (S259, S260); and

a second positive powered lens element (E232)

25   between the first positive powered lens element (E231)

and said boundary lens (E233), and having at least one aspheric optical surface (S261, S262).

4.   The projection optical system of any one of Claims 1 to 3 further comprising a double-Gauss anastigmat arranged to reduce spherical aberration including a third positive powered lens element (E222), a first negative powered lens element (E223), a second negative powered lens element (E224), and a fourth positive powered lens element (E225).

5.   The projection optical system of any one of Claims 1 to 4 further comprising a catadioptric anastigmat comprising a concave mirror (E215) and at least one negative powered Schupmann lens (E213, E214).

6.   The projection optical system of Claim 5 wherein the catadioptric anastigmat comprises two negative powered Schupmann lenses (E213, E214).

7.   The projection optical system of any one of Claims 1 to 6 adapted for use with ultraviolet light.

8.   A projection optical system for projecting an image of a first plane (OP) to a second plane (IP) comprising:

    an optical system;

    a boundary lens (E233); and

    at least one layer of immersion liquid (IL) between said boundary lens (E233) and said second plane (IP); wherein

light from the first plane (OP) is transmitted through the optical system, and output with a predetermined marginal ray convergence angle (L); and

said boundary lens (E233) is positioned to receive said light output from the optical system, and adapted such that for light projected onto the second plane (IP) through the boundary lens (E233) the marginal ray convergence angle (L) prior to incidence is larger than the marginal ray convergence angle (S) within said boundary lens (E233).

9.   The projection optical system according to Claim 8 wherein the optical system comprises:

at least one positive powered lens element (E231, E232) proximal to said boundary lens (E233), and having an aspheric optical surface (S259, S260, S261, S262).

10.   The projection optical system of Claim 8 wherein the optical system comprises:

a first positive powered lens element (E231) proximal to said boundary lens (E233), and having at least one aspheric optical surface (S259, S260); and

a second positive powered lens element (E232) between the first positive powered lens element (E231) and said boundary lens (E233), and having at least one aspheric optical surface (S261, S262).

11.   The projection optical system of any one of Claims 8 to 10 wherein the optical system comprises:

a double-Gauss anastigmat arranged to reduce spherical aberration including a third positive powered lens element (E222), a first negative powered lens element (E223), a second negative powered lens element

5   (E224), and a fourth positive powered lens element (E225).

12. The projection optical system of any one of Claims 8 to 11 wherein the optical system further comprises a catadioptric anastigmat comprising a concave mirror

10   (E215) and at least one negative powered Schupmann lens (E213, E214).

13. The projection optical system of Claim 12 wherein the catadioptric anastigmat comprises two negative powered Schupmann lenses (E213, E214).

15   14. The projection optical system of any one of Claims 8 to 13 adapted for use with ultraviolet light.

15. A method of projecting an image of a first plane onto a second plane (IP) including the steps of:

passing light having a first marginal ray

20   convergence angle (L) to a boundary lens (E233);

passing light having a second marginal ray convergence angle (S) though the boundary lens (E233); and

passing light from said boundary lens (E233)

25   through a layer of immersion liquid (IL) to the second plane (IP); wherein

the first marginal ray convergence angle (L) is greater than the second marginal ray convergence angle (S).

16. The projection method of Claim 15 including the step of passing light through at least one positive powered lens element (E231, E232) proximal to said boundary lens (E233), and having an aspheric optical surface (S259, S260, S261, S262).

17. The projection method of Claim 15 including the steps of:

passing light through a first positive powered lens element (E231) proximal to said boundary lens (E233), and having at least one aspheric optical surface (S259, S260); and

passing light through a second positive powered lens element (E232) between the first positive powered lens element (E231) and said boundary lens (E233), and having at least one aspheric optical surface (S261, S262).

18. The projection method of any one of Claims 15 to 17 further including the step of passing light through a double-Gauss anastigmat arranged to reduce spherical aberration including a third positive powered lens element (E222), a first negative powered lens element (E223), a second negative powered lens element (E224), and a fourth positive powered lens element (E225).

19. The projection method of any one of Claims 15 to 18 including the step of passing light through a catadioptric anastigmat comprising a concave mirror (E215) and at least one negative powered Schupmann lens (E213, E214).

20. The projection method of Claim 19 including the step of passing light through two negative powered Schupmann lenses (E213, E214).

21. The projection method of any one of Claims 15 to 20 wherein said light is a beam of ultraviolet light.

22. An exposure apparatus comprising an illuminating system for illuminating a mask set on the first plane (OP), and a projection optical system according to any one of Claims 1 to 21 for forming an image of a pattern formed on said mask on a photosensitive substrate set on the second plane (IP).

23. An exposing method comprising the steps of illuminating a mask set on the first plane (OP), and projecting and exposing a pattern image formed on said mask on a photosensitive substrate set on the second plane (IP) via the projection optical system according to any one of Claims 1 to 21.

24. A projection optical system for projecting an image of a first plane (OP) onto a second plane (IP), comprising:

an optical path having a plurality of lenses including a boundary lens which is arranged at a position closest to the second plane, wherein the first plane (OP) side surface of the boundary lens has a positive refractive power, and for an atmosphere in said optical path having a refractive index of 1, the optical path between said boundary lens and said second plane (IP) is filled with a medium having a refractive index larger than 1.1.

25. The projection optical system according to Claim 24, which satisfies the condition as expressed by:

$$0.012 < Cb \cdot D/NA < 0.475$$

where, Cb represents the curvature of said boundary lens on the first plane (OP) side; D represents the distance between an optical axis and the outermost point of an effective image forming area, and NA represents the numerical aperture on the second plane (IP) side of the boundary lens.

26. The projection optical system according to Claim 24 or 25, wherein at least one optical member (Lp) having substantially no refractive power is arranged in the optical path between said boundary lens and said second plane (IP); and the optical path between said boundary lens and said optical member, and the optical path between said optical member and said second plane (IP) are filled with said medium.

27. The projection optical system according to Claim 26, wherein said at least one optical member having substantially no refractive power is detachably arranged in the optical path between said boundary lens and said second plane (IP).

28. The projection optical system according to Claim 26 or 27, wherein the optical member having substantially no refractive power has an adjustable orientation.

29. The projection optical system according to any one of Claims 26 to 28, wherein said projection optical system satisfies the condition as expressed by:

$$|P \cdot D| < 1.0 \times 10^{-4}$$

where, P represents the refractive power of said optical member having substantially no refractive power, and D represents the distance between the optical axis and the outermost point of the effective image forming area.

30. The projection optical system according to any one of Claims 24 to 29, wherein said projection optical system is a catadioptric optical system comprising at least one concave reflector.

31. The projection optical system according to Claim 30, having an effective image forming area eccentric relative to the optical axis, wherein at least one

intermediate image is formed in said optical path of said projection optical system.

32. The projection optical system according to Claim 31, comprising one image forming optical system (G2), having said at least one concave reflector, for forming said intermediate image; and another image forming optical system (G3) for forming a final image on said second plane (IP) on the basis of the flux from said the intermediate image; and

a deflecting mirror arranged in the optical path between said one image forming optical system and said another image forming optical system.

33. The projection optical system according to Claims 32, wherein the following conditional expression is satisfied:

$$0.75 < MA/MG3 < 1.1$$

where, MA denotes a magnification of the whole optical system, and MG3 denotes a magnification of the another imaging optical system (G3).

34. The projection optical system according to Claim 31, comprising a first image forming optical system (G1) for forming a first intermediate image of said first plane (OP); a second image forming optical system (G2), having said at least one concave reflector, for forming a second intermediate image on the basis of said first intermediate image; and a third image

forming optical system (G3) for forming a final image on said second plane (IP) on the basis of the flux from said second intermediate image; wherein:

a first deflecting mirror is arranged in the optical path between said first image forming optical system and said second image forming optical system; and a second deflecting mirror is arranged in an optical path between said second image forming optical system and said third image forming optical system.

35. The projection optical system according to Claim 34, wherein the optical axis of said first image forming optical system is aligned with the optical axis of said third image forming optical system.

36. The projection optical system according to Claim 34 or 35, wherein the following conditional expression is satisfied;

$$0.75 < MA/MG3 < 1.1$$

where, MA denotes a magnification of the whole optical system, and MG3 denotes a magnification of the third imaging forming optical system (G3).

37. The projection optical system according to Claims 32 or, wherein said another image forming optical system (G3) includes an aperture stop, and wherein the number of lens elements arranged on the second plane (IP) side of the aperture stop is five or less.

38. The projection optical system according to Claims 37, wherein all lens elements arranged between the second plane (IP) and the aperture stop in the third image forming optical system have positive refractive power.

39. The projection optical system according to Claims 37, wherein no lens element having negative refractive power is included in the lens elements arranged in the second plane (IP) side of the aperture stop.

40. The projection optical system according to any one of Claims 24 to 39, wherein the numerical aperture on the first plane (OP) side is 0.22 or larger.

41. The projection optical system according to any one of Claims 24 to 40, wherein the light quantity loss occurring upon passing through said medium is 50% or lower.

42. An exposure apparatus comprising an illuminating system for illuminating a mask set on a first plane (OP), and a projection optical system according to any one of Claims 24 to 41 for forming an image of a pattern formed on said mask on a photosensitive substrate set on said second plane (IP).

43. An exposing method comprising the steps of illuminating a mask set on a first plane (OP), and projecting and exposing a pattern image formed on said mask on a photosensitive substrate set on a second

plane (IP) via the projection optical system according

to any one of Claims 24 to 41.

Fig. 1

Fig.2

Fig.3

3/20

R233

IL

S263   S264

IP
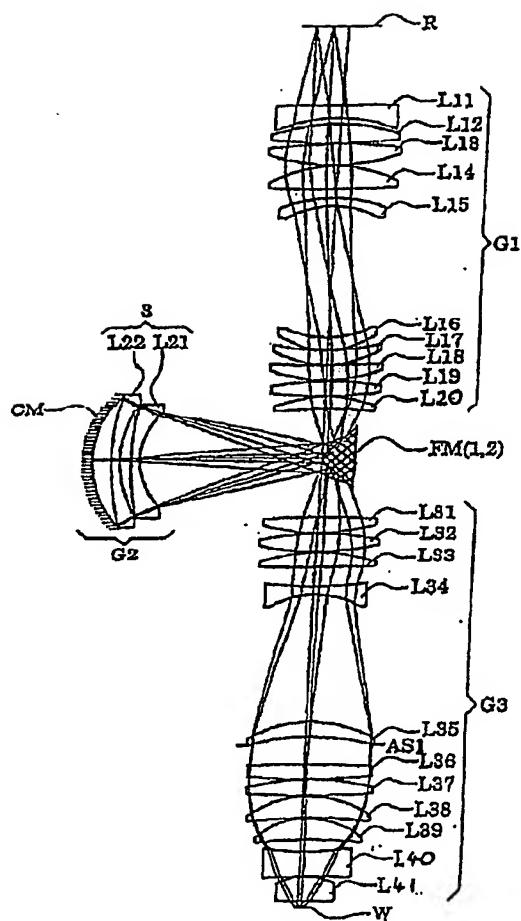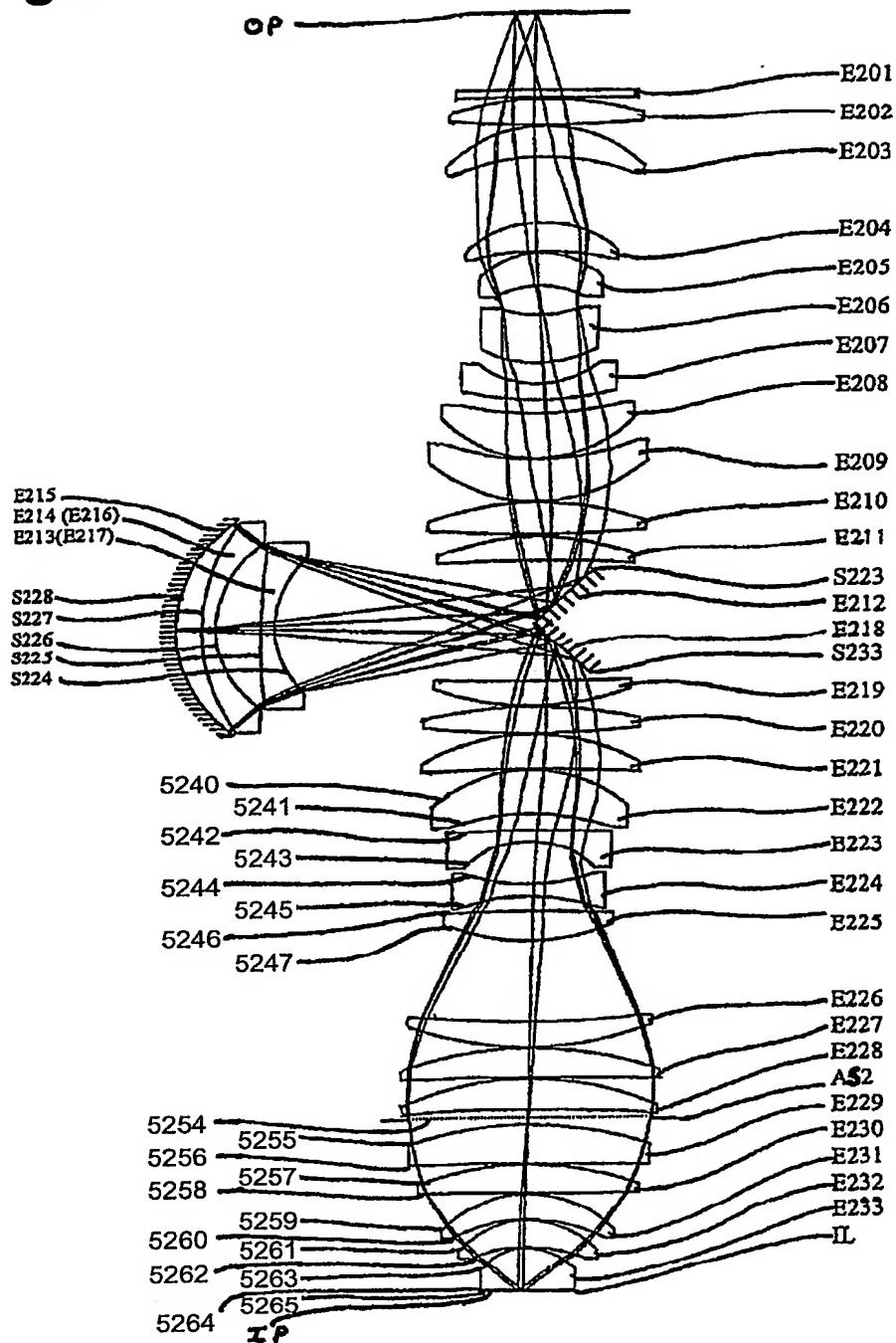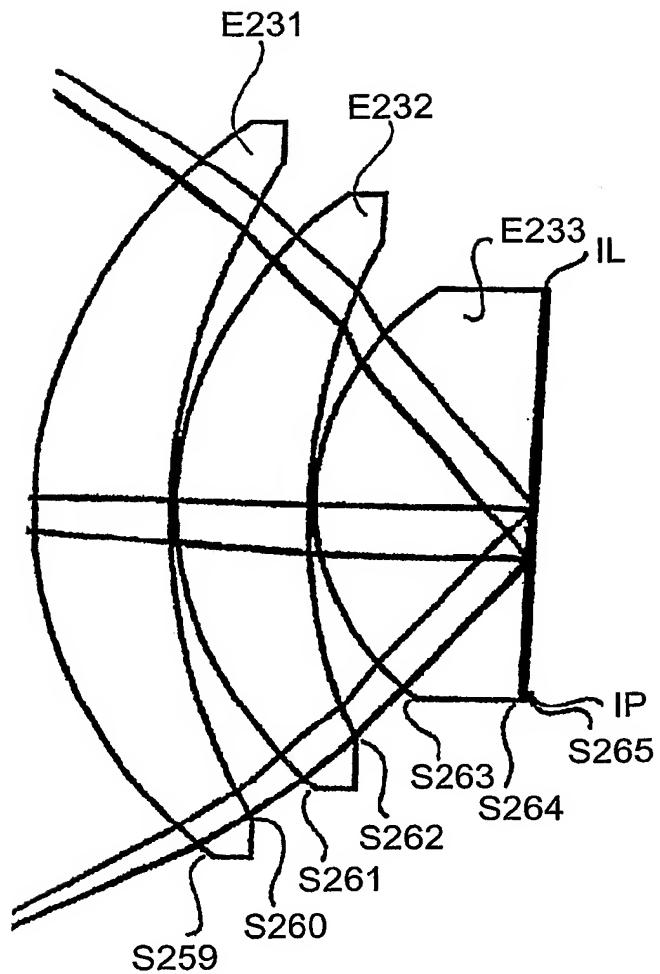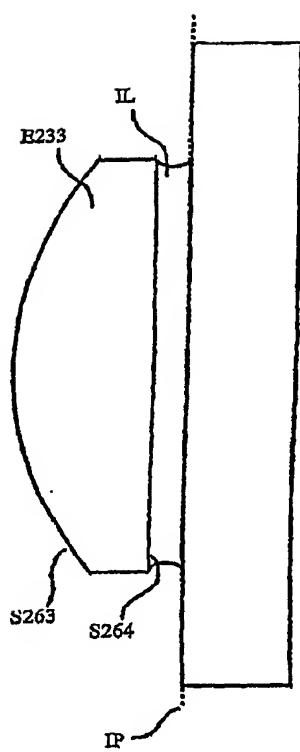
Fig. 4
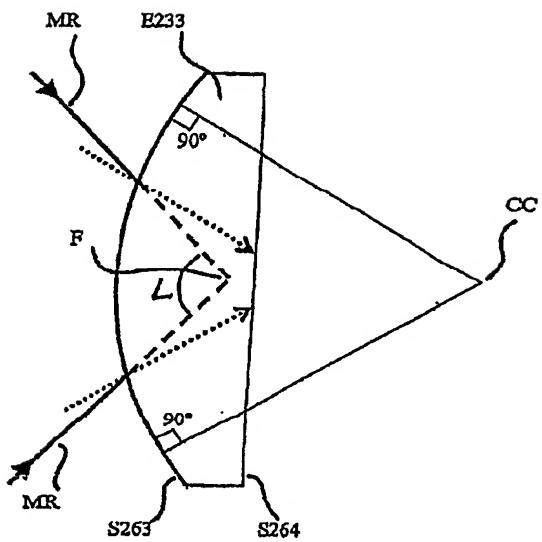
Fig. 5
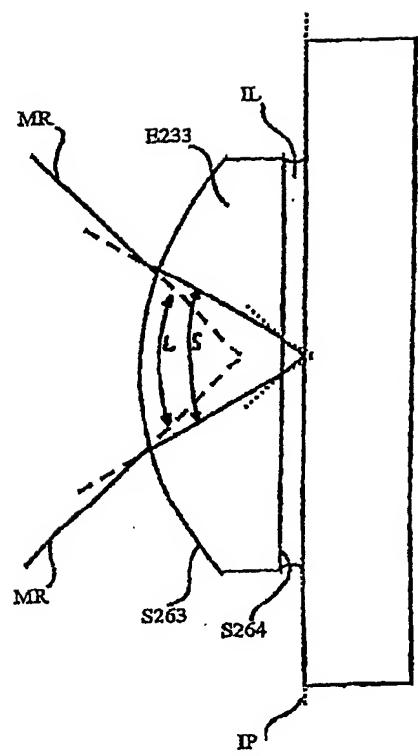
Fig. 6
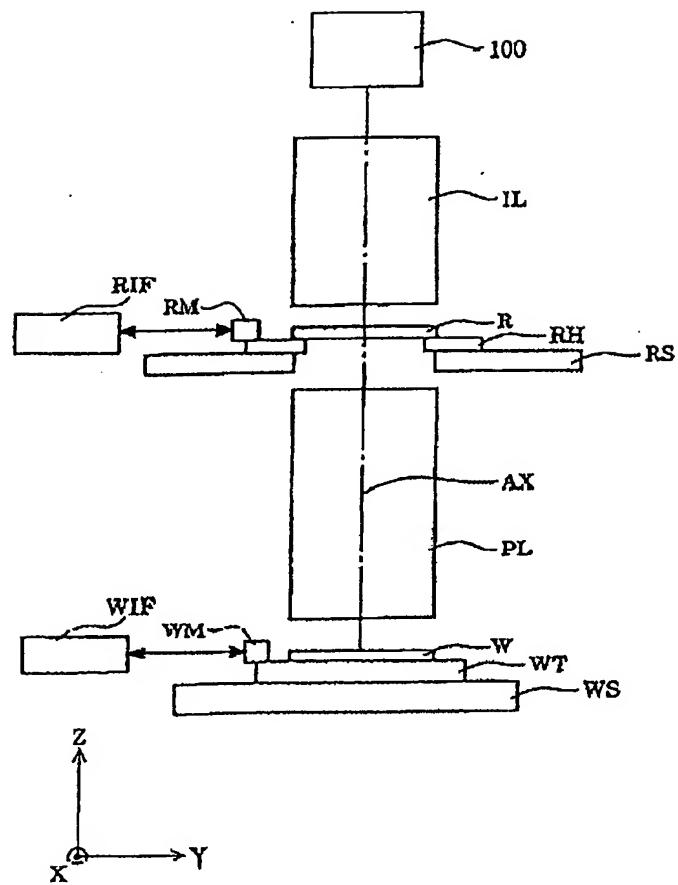
Fig. 7
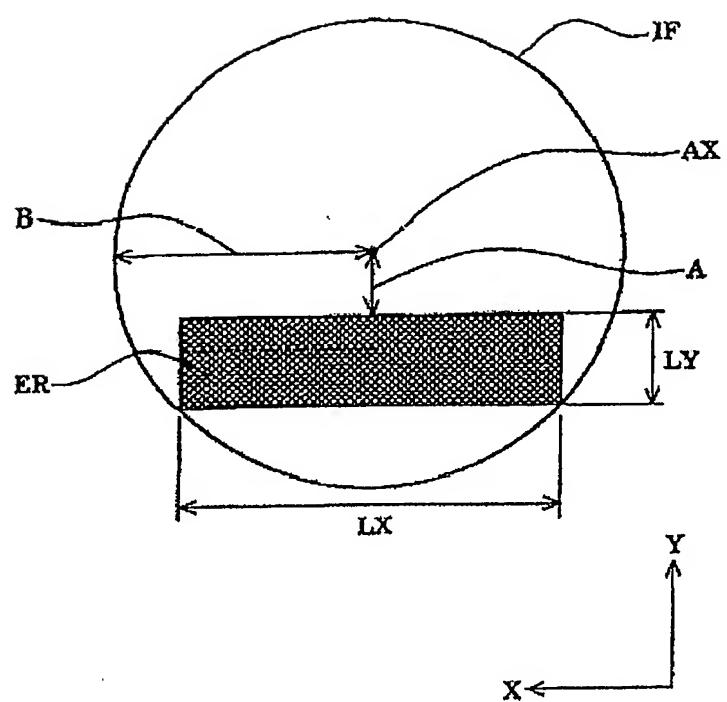
Fig. 8
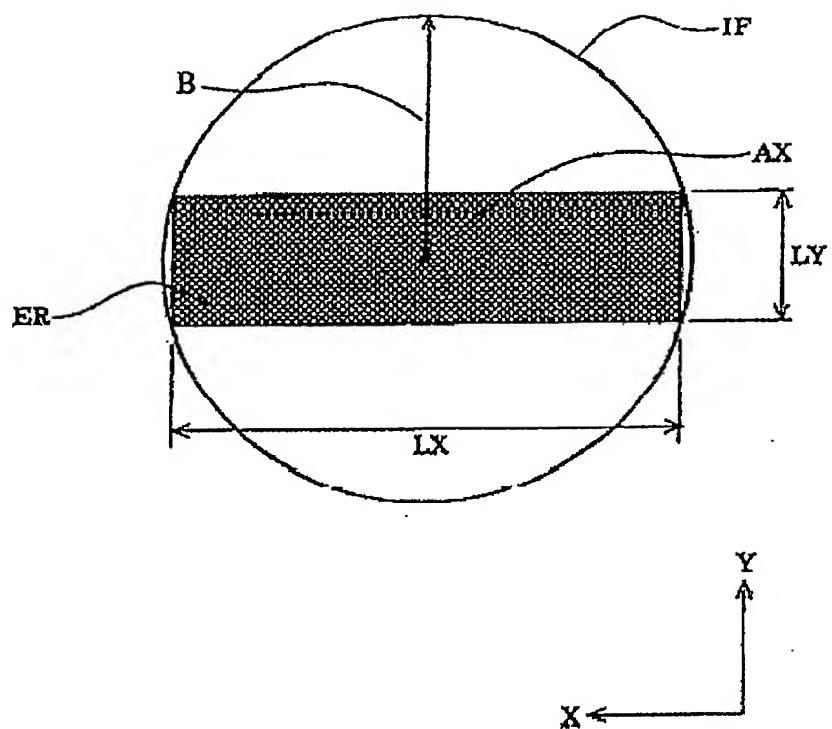
Fig. 9

Fig. 10

Fig. 11
11/20

Fig.12

LATERAL ABERRATION

MERIGIONAL   SAGITTAL

0.0002   Y=15mm   0.0002

-0.0002   -0.0002

0.0002   Y=9mm   0.0002

-0.0002   -0.0002

0.0002   Y=3mm   0.0002

-0.0002   -0.0002 (mm)
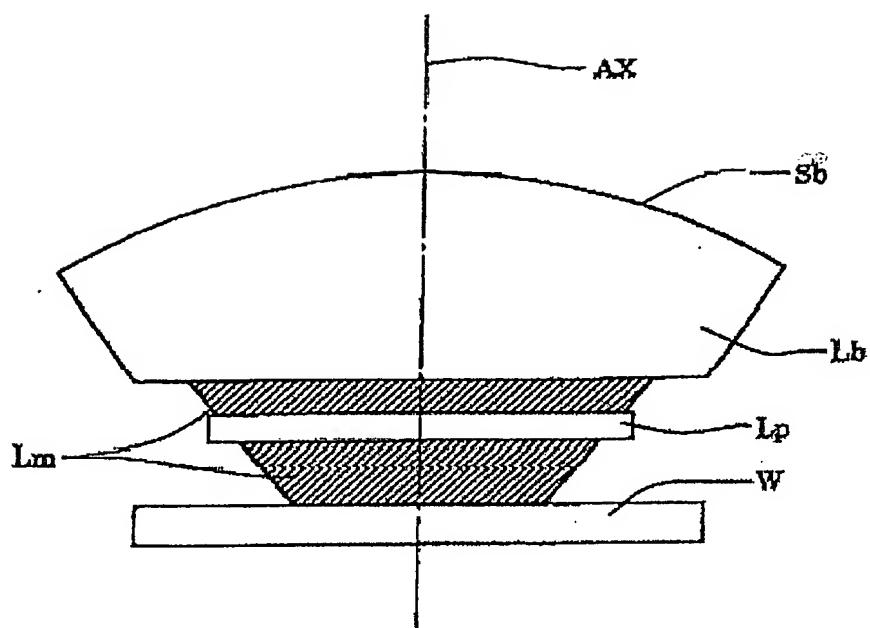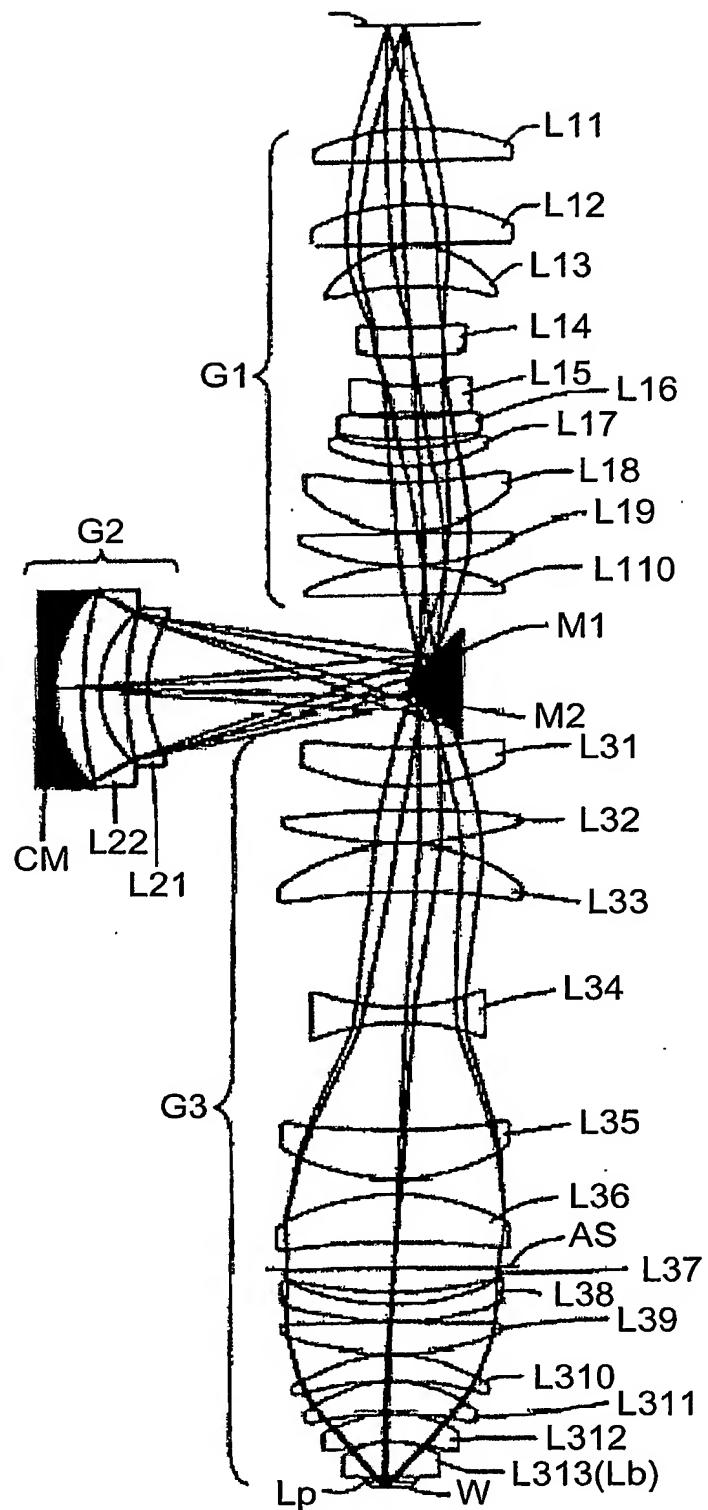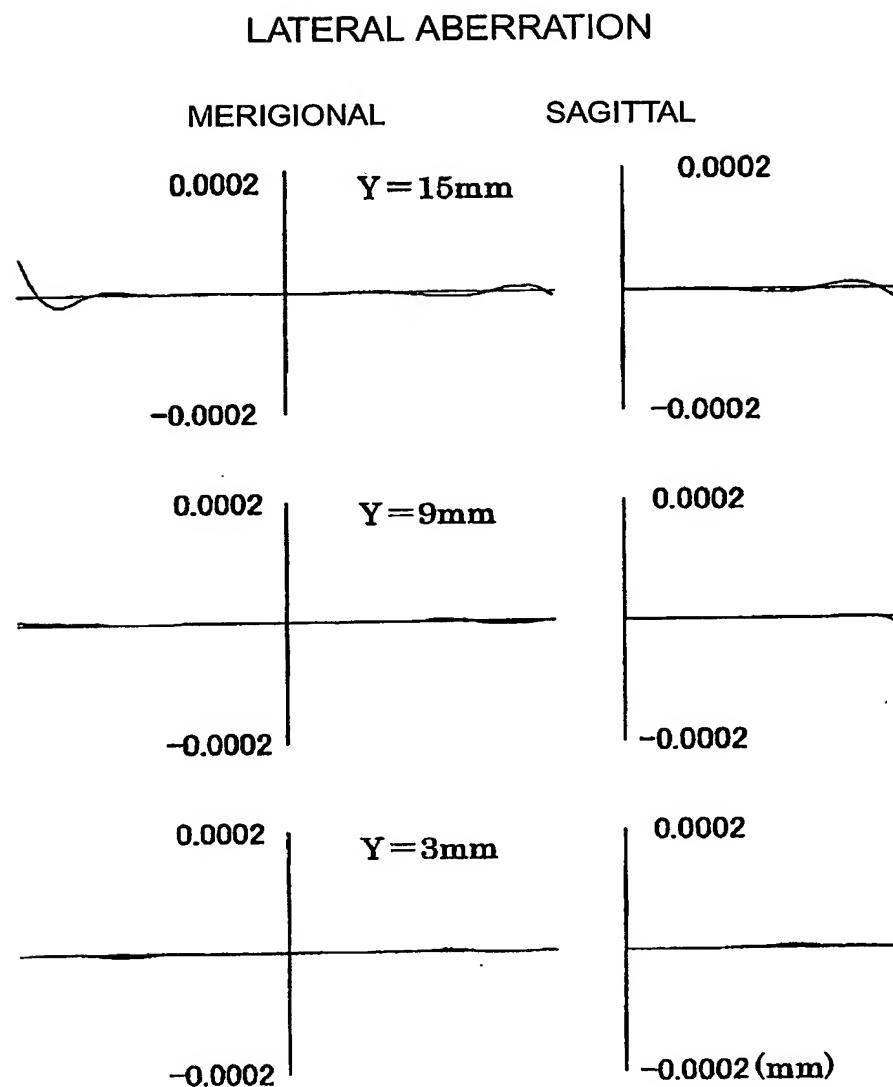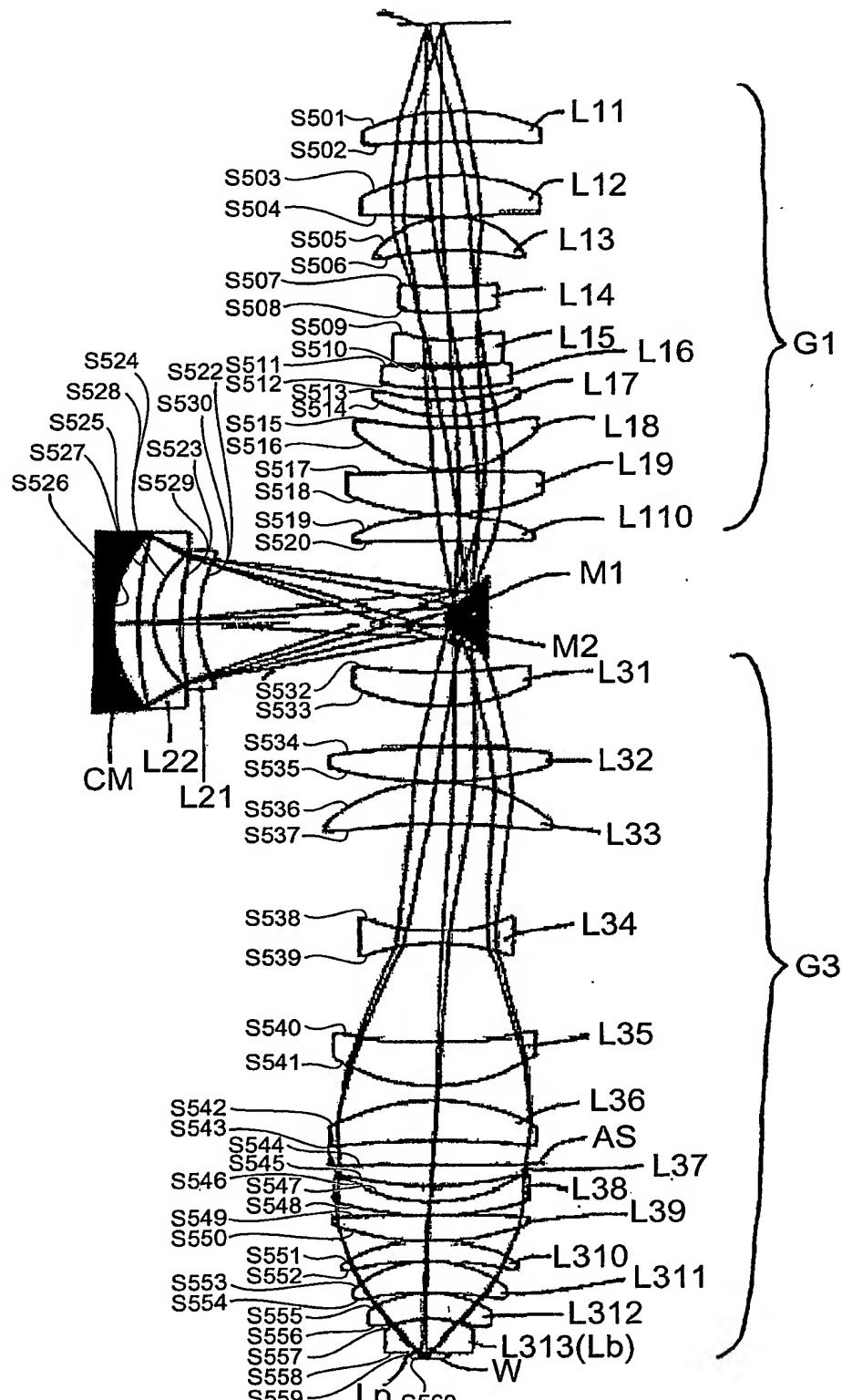
Fig. 13

13/20

Lateral Aberration

Fig. 14

R

L11
L12
L13
L14
L15
L16
L17
L18
L19
L110
L111
L112
L113
L114
L115
L116

AS

L117
L118
L119

L120
L121
L122
L123(Lb)
Lp W

Fig. 15

15/20

Lateral Aberration

Meridional   Sagittal

Fig. 16

```
                        ┌──────────────────┐
                        │      Start        │
                        └──────────────────┘
                                 │
                                 ▼                              301
        ┌──────────────────────────────────────────────────┐
        │   Vapour deposit metal films onto wafers of one batch │
        └──────────────────────────────────────────────────┘
                                 │
                                 ▼                              302
        ┌──────────────────────────────────────────────────┐
        │     Coat metal films on wafer with photoresist      │
        └──────────────────────────────────────────────────┘
                                 │
                                 ▼                              303
        ┌──────────────────────────────────────────────────┐
        │  Sequentially expose pattern images on masks and transfer to │
        │  individual shot areas on wafers using exposure apparatus of │
        │                      invention                      │
        └──────────────────────────────────────────────────┘
                                 │
                                 ▼                              304
        ┌──────────────────────────────────────────────────┐
        │           Develop photoresist on wafers             │
        └──────────────────────────────────────────────────┘
                                 │
                                 ▼                              305
        ┌──────────────────────────────────────────────────┐
        │  Perform etching with resist pattern as masks on wafers to form │
        │     circuit patterns in the individual shot areas    │
        └──────────────────────────────────────────────────┘
                                 │
                                 ▼
                        ┌──────────────────┐
                        │       End         │
                        └──────────────────┘
```

Fig. 17

```
                        ┌─────────────────┐
                        │      Start      │
                        └─────────────────┘
                                 │
                                 │                          401
                                 ▼
        ┌────────────────────────────────────────────┐
        │          Perform photolithography           │
        └────────────────────────────────────────────┘
                                 │
                                 │                          402
                                 ▼
        ┌────────────────────────────────────────────┐
        │              Form colour filters            │
        └────────────────────────────────────────────┘
                                 │
                                 │                          403
                                 ▼
        ┌────────────────────────────────────────────┐
        │               Assemble cells                │
        └────────────────────────────────────────────┘
                                 │
                                 │                          404
                                 ▼
        ┌────────────────────────────────────────────┐
        │              Assemble modules               │
        └────────────────────────────────────────────┘
                                 │
                                 ▼
                        ┌─────────────────┐
                        │       End       │
                        └─────────────────┘
```

Fig. 18

Reticle(First Plane)

S601 L11
S602
S603
S604 L12
S605
S606
S607 L13
S608
S609 L14
S610
S611 L15
S612
S613 L16
S614
S615 L17
S616
S617 L18
S618
S619 L19
S620
L110

G1

G2
CM L22 L21

S626
S625
S627
S624   S623
S628   S629
       S622
       S630

S632 L31
S633 L32
S634
S635 L33
S636
S637 L34
S638
S639 L35
S630
S631 L36
S632
S633 L37
S634
S635

S636 L38
S637
S638 L39
S639
S640 L310
S641
S642 AS
S643
S644 L311
S645
S646 L312
S647
S648 L313
S649 L314
S650
S651 L315
S652

G3

Fig.19

19/20   Wafer(Second Plane)

SUBSTITUTE SHEET (RULE 26)

Fig.20

LATERAL ABERRATION